METALLURGIA

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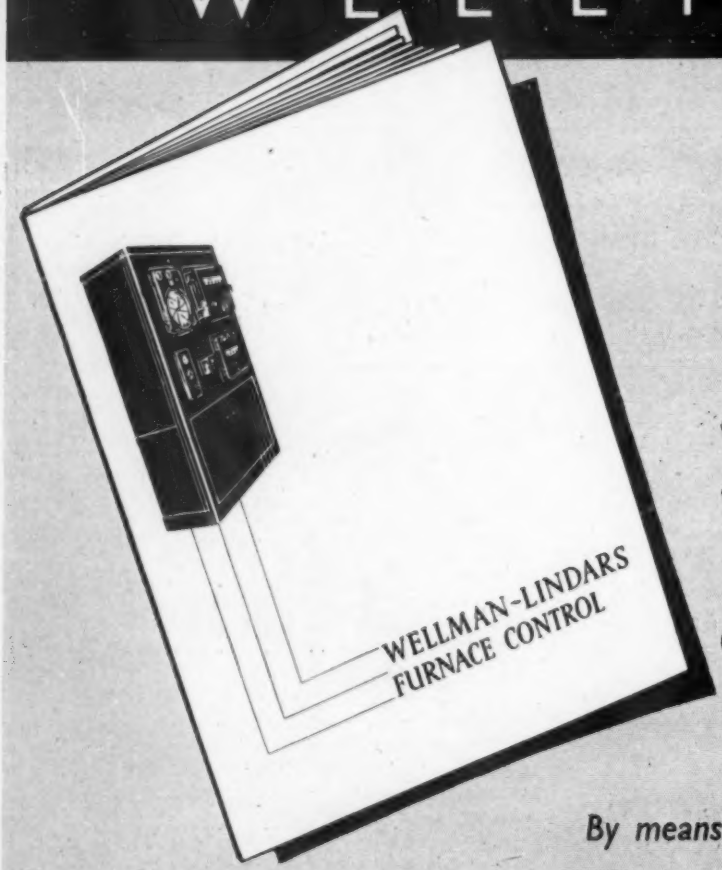

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METALLURGIA

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MARCH, 1947 VOL. XXXV No. 209

A Plan to Modernise and Develop the South Wales Sheet and Tinplate Industries

EVENTS have so crowded upon each other and have moved so swiftly in the past few months, that we are liable to forget that whatever short-time plans may be put into operation to meet the present emergency should not in any way retard approved long term plans nor interfere with the proper consideration of long term plans designed to restore sections of an industry to an efficient and economic standard of production. In the iron and steel industry, for instance, it will be remembered that the general scheme of reorganisation planned by the British Iron and Steel Federation, subsequently published as a White Paper, included a suggested allocation for the modernisation of the industry in South Wales.

Details of a scheme were given recently by Mr. E. H. Lever, chairman of Richard Thomas & Baldwins, Ltd., at a meeting of the Port Talbot and Aberavon Chamber of Trade, concerning new steel sheet and tinplate plants to be erected in South Wales in order to complete the modernisation of the tinplate and sheet industry in this area. The first stage of this modernisation began a decade ago at Ebbw Vale and now details have been worked out, and the various firms have reached agreement not only upon technical detail but upon the administrative and legal structure best calculated to carry out the complete scheme with efficiency and speed. It is noteworthy that the scheme, which is likely to cost about £50 million, has received the unqualified approval of the Iron and Steel Federation. It forms part of the Federation's £200 million five-year plan for the modernisation of the iron and steel industry as a whole, but the approval of the Steel Board had not been given at the time of writing.

The scheme consists of the erection of a huge continuous hot-strip mill, capable of rolling over a million tons a year of hot strip up to 72 in. wide, and three cold-reduction mills. The latter will have tinning plant incorporated with them, the whole being designed and equipped to largely displace the older type hand tinplate mills of Wales. Famous companies, including Richard Thomas & Baldwin's, Ltd., Guest Keen & Baldwins Iron & Steel Co., Ltd., Guest Keen Nettlefolds, Ltd., Llanelly Associated Tinplate Companies, Ltd., and John Lysaght, Ltd., have met and hammered out a solution which should prove of the greatest benefit to industry and to Wales. The co-operation of these companies, which has involved sacrifices of personal interest, made it possible for Mr. Lever to embark on the task of forming a new company to be known as the Steel Company of Wales. This new company is to have the responsibility of planning, erecting and managing the new hot strip and cold-reduction plants and of selling their products in home and overseas markets.

The new Company will take over most of the old-type tinplate works owned by Richard Thomas & Baldwins, Llanelly Associated Tinplate Companies and the sheet works at Newport of John Lysaght, Ltd., so that production programmes can be fully co-ordinated and the problems of obsolescence and redundancy dealt with in an orderly way and with a minimum of dislocation and hardship when the new plants come into operation.

The hot-strip mill will be based at the Port Talbot and Margam Works, at present owned by Guest Keen Baldwins Iron & Steel Co., Ltd., which will be acquired by the proposed new Company and incorporated in the development scheme. Guest Keen & Baldwins has for long contemplated the erection of a continuous hot-strip mill at Margam, and it is not a surprise to learn that this project has priority in the plans of the new Company. It is proposed that two of the reduction mills, with appropriate tinning facilities, will be at Llangyfelach in the Swansea district and at Trostre in the Llanelly area. The construction of these two mills may not be commenced simultaneously, but the ultimate objective is to have two tinplate cold reduction plants. The site for the third cold-reduction mill, which will produce cold-reduced sheets including extra wide sheets, has not yet been decided, although it will be either near the hot mill at Port Talbot or at Newport.

Mr. Lever gave some additional interesting facts concerning the venture; one important point being that the land to be used is low grade from an agricultural point of view. Estimates of the difference in costs between the products of the new mills, when they are in full production, and the products of the hand mills were not revealed, but the aim is that consumers shall share in any economics that can be effected. Among the interesting facts mentioned were: The output of the Port Talbot and Margam coke ovens and blast furnaces will be doubled. The ingot production of these Works will be trebled as a result of the erection of the new melting shop at Margam. The hot-strip mill will have an output of 20,000 tons a week. It is proposed that the hot-strip mill will roll a coil weighing 15,000 lb. which is a larger coil than is at present rolled anywhere in the world. The horse-power necessary for driving such a mill will be greater than hitherto employed, even in the United States. The main feature of the Swansea and Llanelly district cold-reduction plants will be their sturdy construction and their high speed—viz., up to 4,000 ft. per min., a speed greatly in excess of that possible with the Ebbw Vale mill. The cold-reduction plants at Llangyfelach and Trostre alone will each require about 2 million gallons of water per day.

South Wales has long been renowned for steel sheet and tinplate, but since the development in America of the continuous cold-reduction method, it has been apparent that the day of the hand mill is over, except for a limited speciality output, and the industry must

not be blinded by the fact that, at the moment, manufacturers of steel sheet and tinplate can sell anything they make. The demand for a better quality sheet and tinplate, at a relatively lower price, is increasing, and it is necessary to anticipate a growing demand for high-quality wide sheets by the motor-car industry and by other consumers. Unless this country goes forward with the erection of modern continuous mills capable of meeting these demands not only will we fail to regain our export markets but home consumers of steel sheet and tinplate will be severely handicapped in their efforts to produce increasing quantities of high-quality products at competitive prices.

The scheme, which has been briefly summarised, is designed to place South Wales in a favourable position to meet these demands. The modern plants contemplated have been developed not only to improve quality, but also to provide more horse-power per man so that the number of man-hours per ton of product can be substantially reduced. When fully operating, the new Company would employ many thousands of people under better working conditions than is possible in the hand mills. The sheet and tinplate industries would be live and more attractive industries, which would appeal to all grades of workers. The building of the plant for this scheme will take at least three years and probably it would be four and a half years before it could be in full operation, time that the country can ill afford to enable us to meet keen competition from overseas which is bound to be experienced. Thus, the sooner a decision can be reached the sooner a start can be made to put these South Wales industries in order.

Sanction to proceed with the scheme involves the question of finance. As Mr. Lever pointed out, the success both of the erection of the new plants and of their subsequent operation will depend on the amount of co-operation the new Company will receive. It needs help and co-operation from many authorities, and from many people—from the local authorities, to whom it will have to look for the provision of many services, from the Coal Board from whom it will require adequate supplies of coal of the right quality and the right price, from the electricity companies or from the Electricity Board from which it will expect satisfactory arrangements for the supply of power, from the railways, for efficient transport at reasonable rates, and from numerous Government Departments, from which it will expect priorities as regards supplies of materials and labour. Most of all, the Company will look hopefully to the Treasury for sympathetic consideration, having regard to the fact that in the national interest it is undertaking the modernisation of plant at a time of high capital costs. Amongst the ways in which they can help is to exempt from import duties that part of the plant which we shall have to obtain from America.

The sheet and tinplate industries in South Wales are too important to the industrial success of the whole country to be neglected, and it is naturally expected that this scheme of modernisation will receive the consideration and support it so much deserves.

Fuel Production and Utilisation

THE Government White Paper, "Economic Survey for 1947" has emphasised the need for production. High efficiency is the essential pre-requisite for high productivity. British industry is based upon coal, but coal is in short supply, and unless fuel and power of every kind are used to the best advantage in every industry we shall not come successfully through the difficult years that lie ahead.

Much has been accomplished in this direction since the turn of the century, but much remains to be done. It has been calculated that an increase of 15% in the coal utilisation efficiency of the whole country would produce an addition to the national income of £200,000,000. These savings cannot be secured only by the correction of obvious faults. They entail new methods of a highly technical character that will require the advice of experts of the highest calibre. The high cost of fuel and power will make it desirable for every business to consider the correct utilisation of heat and energy in existing works, and also to take fuel efficiency prominently into account when designing new works, especially new plant and melting or other furnaces. Expert advice is the more necessary since the efficient use of fuel may necessitate considerable capital expenditure. There is a great deal of accumulated knowledge on this subject; if more use were made of that knowledge, large sums of money and millions of tons of coal could be saved.

Because of the importance which attaches to this problem in all countries, the Powell Duffryn group have decided to set up a new organisation to give practical help to industry in all matters of fuel production and utilisation. For this purpose a new company has been formed, known as Powell Duffryn Technical Services, Ltd., having at its head Mr. Robert Foot, lately Chairman of the Mining Association of Great Britain and a Managing Director of the Group.

The main objects of this new organisation are twofold: First, to place at the disposal of industrial undertakings a highly qualified and impartial advisory and consultant service in connection with the efficient and economical use of all types of fuel for all industrial purposes and processes. This will, of course, be complementary to the valuable work being done by the Fuel Efficiency Division of the Ministry of Fuel and Power. The new service will tackle the problem of heat and power utilisation in the individual factory. It will investigate and advise on the changes to be made and the economies to be achieved, arrange and supervise the installation, where necessary, of new plant, and generally see the job through from beginning to end; and second, to act as consultants on any aspect of coal mining anywhere in the world. Whatever the future may hold for us in the way of atomic energy for industrial purposes, it seems abundantly clear that for very many years to come we shall still be living in the age of coal and oil and that the whole world will continue to depend for raising its standard of living upon the ample and economic production of these fuels.

There can be no doubt that the recent crisis has convinced us of our duty to regard coal as our most precious asset and the basis of our whole recovery programme, it behoves us, therefore, to distribute and use it with the maximum efficiency, and this organisation should be able to contribute considerably to this end.

Essential Considerations in Furnace Usage and Design

By Herbert Southern, F.Inst.F., A.M.I.Mech.E., M.Am.Soc.M.E.

Managing Director, G. P. Wincott, Ltd., Sheffield.

Present conditions necessitate maximum efficiency in regard to output and quality of products on a minimum expenditure of fuel, auxiliary power, labour and maintenance. No longer can we disregard the need for care in the design and construction of industrial furnaces for the melting, reheating and heat-treatment of metals to achieve these desirable ends. This calls for a knowledge of fuels and their combustion ; of heat transfer, thermodynamics and aerodynamics ; of diverse manufacturing processes ; of the physical changes and chemical reactions that occur during these processes ; and of the properties of refractory and heat-resisting materials. Some of these factors were discussed by the author in a recent paper before the Sheffield Metallurgical Association and, in view of its importance, his critical consideration of the subject is given in full.

THE design and construction of industrial furnaces for the melting, reheating and thermal treatment of metals is a subject of greater complexity than is generally realised. It demands a most careful appraisal of the combined effect upon life and operation, of many interdependent factors, and this calls for a knowledge of fuels and their combustion ; of heat transfer, thermodynamics and aerodynamics ; of diverse manufacturing processes ; of the physical changes and chemical reactions that occur during these processes ; and of the properties of refractory and heat-resisting materials. It requires, in fact, a wide knowledge of the industrial sciences, together with a sound practical experience of manufacturing requirements, but even then is a problem beset with difficulties and pitfalls.

There are nevertheless, certain people who still regard furnaces in general as mere boxes of brickwork that any jobber can build and the cheapest unskilled labour can operate. This is an astounding opinion which cannot long be tolerated.

It should now be clear to all that fuel must be conserved and this demands the correct use of scientifically designed furnaces of sound construction. There are, however, limits to the degree of achievement in fuel conservation. It is, for instance, just as foolish to think that a thermal efficiency of 100% can be attained as to believe that a jobber without scientific knowledge can guarantee the performance of his unbalanced structures.

Industry, in general, needs furnaces of optimum efficiency, capable of consistently maintaining the desired output and quality of product on a minimum expenditure in fuel, auxiliary power, labour and maintenance. Economical production is the vital and prime essential, and this is also the national need despite the persistent demand of the Ministry of Fuel and Power for fuel economy alone.

The Efficiency of Furnaces

The appraisal of the optimum efficiency of a furnace is much more difficult than the determination of its thermal efficiency, and this accounts for the general practice of comparing the performance of furnaces on the relative consumptions of fuel per ton or per unit of product. Let us, therefore, consider the many factors which influence and control the thermal efficiency of furnaces.

The heat content of a ton of steel at a temperature of 850° C. (1,562° F.) is about 577,000 B.T.U. At 1,000° C. (1,832° F.) it is approximately 685,000 B.T.U., and at 1,250° C. (2282° F.) it is about 860,000 B.T.U. Now if furnaces of 100% efficiency were available for the heating of the steel, then the consumption of fuel to raise the material to the stated temperatures would obviously be a minimum.

On the basis of the nett calorific value of different fuels it would be as follows :—

TABLE I.

Final Temperature of Steel °C.	850°	1,000°	1,250°
Heat Content per ton B.T.U.	577,000	685,000	860,000
Coal—12,780 gross/12,410 nett B.T.U. lb.	46·5 lb.	55·1 lb.	69·2 lb.
Fuel Oil—19,310 gross/18,013 nett B.T.U. lb.	32·0 lb.	38 lb.	47·7 lb.
Coke Oven Gas—478 gross/428 nett B.T.U. cu. ft.	1,350 cu.ft.	1,600 cu. ft.	2,010 cu. ft.
Raw Producer Gas at 315° C.—158 gross/149 nett B.T.U. cu. ft.	3,875 cu.ft.	4,600 cu. ft.	5,770 cu.ft.
City Gas—496 gross/455 nett B.T.U. cu. ft.	1,270 cu.ft.	1,506 cu. ft.	1,890 cu. ft.

(This Table relates to carbon steels)

It is, of course, impossible to build furnace structures which neither absorb nor dissipate thermal energy, but even if it were, it would still be impossible to liberate and fully utilise within the heating chambers the total heat content of the fuel consumed. The figures of fuel consumption given in Table I are, therefore, unattainable. They are, nevertheless, useful as a yardstick in the determination of the approximate thermal efficiency of existing furnaces. Suppose, for instance, that a simple coal-fired furnace solely employed for the batch heating of cold steel to 1,250° C., consumes 692 lb. of coal per ton of heated material during a reasonable period of observation, then its average thermal efficiency is 10% because the consumption is ten times greater than the computed figure for an ideal furnace of 100% efficiency. In other words, 90% of the heat energy of the fuel is dissipated.

The main reasons for the waste of fuel are enumerated below :—

1. Evaporation and superheating of the moisture in the coal.
2. Heating of the ash in the fuel.

3. Loss of combustible matter in the refuse from the ash-pit.
4. Radiation of heat through the firing door opening.
5. Absorption and dissipation of heat by the walls and casing of the firebox.
6. Improper oxidation of the fuel and incomplete liberation of its latent heat.
7. A deficiency or excess of air during combustion.
8. Absorption and dissipation of heat by the walls and casing of the heating chamber.
9. Radiation of heat through the door openings of the heating chamber.
10. Unsatisfactory draught conditions with the infiltration of cold air or the emission of hot gases through ill-fitting doors and through cracks in the furnace brickwork.
11. The controlling influence of the thermal process upon the temperature of the waste products of combustion at the outlet ports of the heating chamber.
12. Incorrect loading of the furnace.
13. Delays in production caused by breakdowns or stoppages in the plant fed by the furnace.
14. Reduced production and lack of proper furnace control during mealtimes and at shift changes.
15. Irregular or intermittent use of the furnace necessitating frequent cooling down and heating up.
16. Carelessness in the maintenance and repair of the furnace.

A general sub-division under different headings of the sixteen contributory factors to the waste of fuel is enlightening :—

(a) *Losses arising from the class and quality of fuel employed.*	Nos. 1 and 2.
(b) *Losses wholly or partially due to the conditions of firing.*	Nos. 3, 4, 6 and 7.
(c) *Losses wholly or partially due to the manner in which the furnace is operated and maintained.*	Nos. 9, 10, 12, 13, 14, 15 and 16.
(d) *Loss due to and inseparable from the particular thermal process.*	No. 11.
(e) *Losses due to the characteristics of the furnace but materially influenced by its state of repair and by the general conditions of operation.*	Nos. 5 and 8.

This analysis shows that thirteen of the sixteen causes of fuel wastage in a crude type of coal-fired forge furnace orise almost entirely from conditions under the control of the user, that one is inherent to the process, and that two are linked with the particular characteristics of the furnace, its general state of repair and the conditions under which it operates.

There is consequently ample opportunity for the saving of fuel in furnaces of the crudest type provided they are capable of producing and maintaining the thermal conditions essential to the processes upon which they are engaged.

Consideration will, therefore, be given to the influence upon fuel consumption of the characteristics of a furnace and of the factors inherent to the heating process.

It has been stated in relation to the simple coal-fired forge furnace that it has an average thermal efficiency of 10% when it consumes 692 lb. of coal in the heating of 1 ton of cold steel to 1,250° C. The heat required by the steel is 860,000 B.T.U. per ton, but additional heat has to be transmitted to the furnace itself to maintain the brickwork at the required operating temperature. The amount depends upon the surface area, thickness, construction and general state of repair of the hearth, walls, and crown ; upon the properties of the refractory materials employed ; and upon the continuous or intermittent operation of the furnace.

In any correctly proportioned furnace of sound normal construction, the heat requirement is a minimum when the brickwork is in thermal equilibrium. It is, for instance, somewhere in the region of 860,000 B.T.U. per hour in a balanced coal-fired furnace capable of heating, under optimum conditions, a maximum of 2 tons of steel per hour to 1,250° C. Thus, in a furnace of this capacity operating at full rating and with the brickwork at the steady state, the hourly heat requirement is :—

Heat absorbed by 2 tons of steel	=	1,720,000
Heat absorbed by the brickwork	=	860,000
Hourly heat requirement	=	2,580,000 B.T.U.

The essential consumption of coal to meet this thermal requirement depends primarily though not solely upon the temperature of the waste gases at the exit ports of the heating chamber and, as previously stated, this temperature is controlled by the purpose or duty of the furnace.

The steel has to be raised to a final temperature of 1,250° C. so the temperature of the furnace must be higher than 1,250° C. Taking a maximum figure of 1,350° C. and allowing for the normal fluctuation in temperature caused by the charging and withdrawal of the steel it is reasonable to assume that the mean temperature of the outgoing waste products of combustion will be in the region of that of the fully heated steel—namely, 1,250° C. If so, then with perfect and complete combustion of the fuel without excess air or subsequent air infiltration the heat content of the products of combustion as they leave the heating chamber will be 6,450 B.T.U. per lb. of coal consumed (excluding the latent heat of water vapour). As the lower calorific value of the coal is 12,410 B.T.U. per lb. then 12,410 − 6,450 or 5,960 B.T.U. are available for use in the heating chamber. Under such perfect conditions of combustion with the furnace operating at full rating and the brickwork in thermal equilibrium, the minimum consumption of fuel to heat 2 tons of steel to 1,250° C. will be :—

$$\frac{\text{Hourly heat requirement}}{\text{Available heat per lb. of coal}} = \frac{2{,}580{,}000}{5{,}960} = 433 \text{ lb.}$$

This is equivalent to 216·5 lb. of coal per ton of steel which represents a thermal efficiency of about 31·25%.

Assuming the same perfect conditions of combustion, together with thermal balance in the brickwork, but the furnace operating at 50% rating, then the fuel consumption per ton of steel will rise to 288 lb. and the efficiency drop to approximately 24%.

If, however, the furnace is intermittently operated, or its general state of repair is bad, or both conditions exist simultaneously then the average hourly heat-requirement of the brickwork may easily be three times greater than that at thermal equilibrium. Under these conditions, even with good thermal release at the firebox, the fuel consumption per ton of steel will rise to 692 lb. and the efficiency drop to 10% if, for instance, the outgoing products of combustion contain 30% excess air and the furnace is operated at 64% rating.

Now such conditions arise in practice, and what is the result ? The furnace is immediately condemned as grossly inefficient.

It is certainly admitted that the furnace cannot achieve a higher thermal efficiency than 31·25% even under ideal conditions of control and operation, and for this reason it is an undesirable unit. If, however, the operating conditions are such that its efficiency is reduced to 10% and 475·5 lb. of coal are wasted during the heating of each ton of steel, then the operating conditions and not the furnace should carry the blame.

The Selection and Appraisal of Fuels

The conservation of fuel in the daily operation of industrial furnaces depends equally upon two things :—

The use of the best available furnaces for the duties to be performed.

The proper maintenance and control of the furnaces after installation.

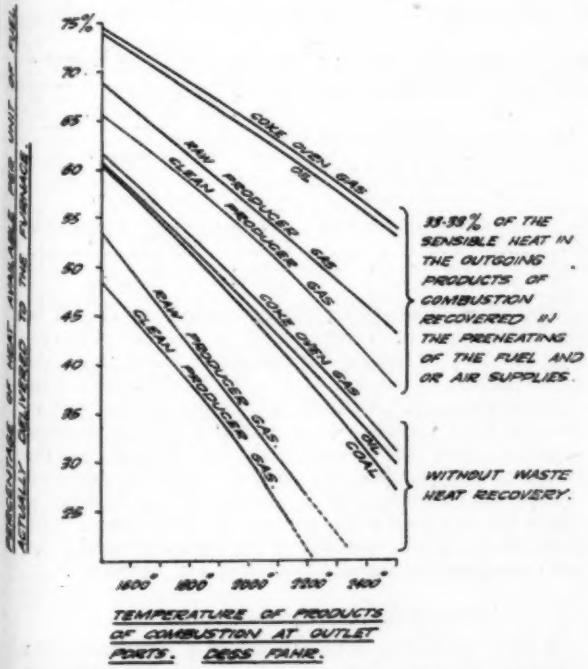


Fig. 1.—Showing the influence of the temperature of outgoing products of combustion upon the percentage of heat available for use per unit of fuel of five different fuels.

When a new furnace is contemplated its purpose is known but its essential characteristics cannot be decided until some conclusion is reached about the class and quality of fuel to be employed.

The prime considerations in the selection of a fuel are :—

1. Suitability.
2. Availability.
3. Low or minimum cost per ton or per unit of production.
4. Cleanliness and convenience in use.

The availability of a particular supply of fuel on or near the site of a furnace is frequently the deciding factor in its adoption and when this is the case, the inherent advantages and disadvantages of the fuel have to be accepted. When, however, there is freedom of choice, consideration should be given to the relative prices, merits and properties of the widest possible range of fuels in order to select the one most likely to give the best results. A preliminary survey of the characteristics of the various fuels now industrially employed will indicate several that appear to be equally suitable for the process under consideration, but further investigation will reduce the number to one or two with definite advantages from the standpoints of control, thermal release, temperature attainment, price and atmospheric suitability. One of these should be selected.

The widespread practice of comparing fuels on the price per therm at the bunker, storage tank or meter, is both erroneous and misleading in relation to their usefulness as heating media. The correct assessment is the cost per therm of the heat actually available for use within the heating chambers. This depends upon a number of factors including the efficiency of combustion, the amount of air employed or infiltrated, and the temperature at which the gases leave the chambers. It is also considerably influenced by the characteristics of the furnace employed.

Fig. 1 has, therefore, been prepared in relation to five different fuels to show the influence of the temperature of the outgoing products of combustion upon the percentage of heat actually available for use per unit of fuel. The five lower curves represent normal conditions of combustion without any recovery of waste heat for the preheating of the fuel and/or air supplies. The four upper curves show the effect of recuperation or regeneration when 33·33% of the heat in the outgoing products of combustion is reclaimed for the preheating of the fuel and/or air supplies. The graph is based upon ordinary fuels of the following characteristics :—

COAL	Gross heating value, 12,780 B.T.U./lb. Nett heating value, 12,410 B.T.U./lb 30% excess air in the outgoing products of combustion.
OIL	Gross heating value, 19,210 B.T.U./lb. Nett heating value, 18,013 B.T.U./lb. 20% excess air in the outgoing products of combustion.
RAW PRODUCER GAS AT 600° F.	Gross heating value, 148 B.T.U./cu. ft. Nett heating value, 139 B.T.U./cu. ft. Sensible heat content, 10 B.T.U./cu. ft. 20% excess air in the outgoing products of combustion.
COLD CLEAN PRODUCER GAS	Gross heating value, 137 B.T.U./cu. ft. Nett heating value, 128 B.T.U./cu. ft. 20% excess air in the outgoing products of combustion.
COKE OVEN GAS	Gross heating value, 478 B.T.U./cu. ft. Nett heating value, 428 B.T.U./cu. ft. 15% excess air in the outgoing products of combustion.

To illustrate the use of the graph, consider a simple coal-fired batch type furnace employed for the reheating of steel. If the waste products of combustion pass direct to the stack at 2,400° F. (1,315° C.) then only 31% of the nett heat content of the coal is available for use within the furnace chamber. In the case of an oil-fired furnace utilising 33·33% of the heat in the waste products of combustion for the preheating of the air supply the heat available is 55·2% of the nett heat content of the oil.

The therms available per ton of fuel consumed in the coal-fired furnace are therefore :—

$$\frac{2{,}240 \times 12{,}410 \text{ B.T.U.} \times 0{\cdot}31}{100{,}000} = 86{\cdot}16$$

The therms available per ton of fuel consumed in the oil-fired furnace are :—

$$\frac{2{,}240 \times 18{,}013 \text{ B.T.U.} \times 0{\cdot}552}{100{,}000} = 222{\cdot}7$$

From this calculation it is clear that the ratio of the price of fuel oil to that of coal must not exceed 222·7 :

86·16, or 2·585:1, if comparable heating costs are desired. The computed ratio also indicates that oil, even at a price of £7 15s. per ton can be just as economical in use as coal at 60s. per ton, when other influencing factors are equal. The illustration stresses the impolicy of assessing the economic value of fuels on the relationship between price and nett calorific value, and also shows the influence of the characteristics of a furnace upon the amount of heat that can be made available.

Temperature Attainment

The various fuels available for industrial use are not equally suitable for the easy attainment and maintenance of certain temperature conditions. This is a vital fact which must never be overlooked in the selection of a fuel for a high temperature process.

The actual temperature attainable from the use of a particular fuel depends upon the calorific value of the fuel, the amount of air employed for combustion, the degree of fuel or air preheating, the conditions of oxidation, the effect of dissociation and to a considerable extent upon the quantity of heat dispersed by radiation. To separate and evaluate the influence of each factor is difficult, but the combined effect is clearly indicated by the results of good practice.

In most furnaces operating at temperatures above 1,350° C. (2,462° F.) from 20–30% of the heat input per unit of the particular fuel employed is ineffectual from the standpoint of temperature generation. For this reason the heat content of the products of combustion per unit of fuel at the point of maximum temperature is only 70–80% of that initially available. The actual temperature of combustion is consequently much lower than many surmise.

To illustrate the point, consider the thermal characteristics of a lean fuel such as blast furnace gas. Fig. 2 shows the heat content of the perfect products of combustion of a typical gas with a nett calorific value of 91·8 B.T.U. per cu. ft. It separately indicates the sensible heat in the gas when preheated and also the heat content of the theoretical air supply at different temperatures.

If it were practicable to utilise the total nett heat energy of the fuel, for the generation of temperature under perfect conditions of combustion without chemical interaction, then a flame temperature of 2,600° F. (1,427° C.) would be attained. Under normal conditions of usage and control such a result is impossible, but in one application, where the gas is consumed with 10% excess air, a temperature of 2,000° F. (1,093° C.) is achieved and maintained. The heat content of the perfect products of combustion at 2,000° F. (1,093° C.) is 66 B.T.U., and the heat content of 10% excess air at the same temperature is 2·5 B.T.U. hence, the total heat content of the products of combustion per cu. ft. of gas is 68·5 B.T.U. or 74.6% of the nett heat content of the fuel. In other words the plant in which the fuel is used has a " pyrometric efficiency " of 74·6%.

It is, of course, frequently necessary to employ straight blast furnace gas for the achievement of higher temperatures than 2,000° F. (1,093° C.). Consider, for instance, the use of the gas in a continuous type steel reheating furnace where a temperature of 1,400° C. (2,552° F.) is required at the forehearth. In such an application the temperature can only be reached and maintained by adequate preheating of the gas, and/or of the air. If combustion takes place with 10% excess air, the heat content of the products per unit of fuel at 1,400° C. (2,552° F.) is 93·3 B.T.U. The thermal input per cu. ft. of blast furnace gas must, therefore, be about 120 B.T.U. for a furnace with a " pyrometric efficiency " of 78%. As the nett heat content of the gas is only 91·8 B.T.U. approximately 28 B.T.U. have to be additionally introduced. Reference to Fig. 2 shows that preheating of the gas to 750° F. (399° C.) will provide 13 B.T.U. and preheating of the theoretical air supply to 1,300° F. (705° C.) will introduce 15 B.T.U. Provided the furnace is correctly designed to ensure these temperatures of preheat the desired combustion temperature at the forehearth will be achieved and maintained.

The approximate temperatures attainable from different fuels, when employed without preheating of either the fuel or the air, in furnaces with an average " pyrometric efficiency " of 75%, are indicated below :—

TABLE II.

Coal—12,780 gross/12,410 nett B.T.U. lb.	1,680° C. without excess air down to 1,400° C. with 30% excess air.
Fuel Oil—19,210 gross/18,013 nett B.T.U. lb.	1,650° C. without excess air down to 1,455° C. with 20% excess air.
Coke Oven Gas—478 gross/428 nett B.T.U. cu. ft.	1,595° C. without excess air down to 1,475° C. with 15% excess air.
Raw Producer Gas at 315° C.—158 gross/149 nett B.T.U. cu. ft.	1,365° C. without excess air down to 1,235° C. with 20% excess air.
Cold Clean Producer Gas—137 gross/128 nett B.T.U. cu. ft.	1,260° C. without excess air down to 1,150° C. with 20% excess air.
Blast Furnace Gas—93·5 gross/91·8 nett B.T.U. cu. ft.	1,150° C. without excess air down to 1,065° C. with 20% excess air.

The effect of excess air during combustion should be carefully observed. Preheating of the fuels or of the air supplies has, of course, a pronounced effect upon the temperatures of combustion—a fact which has been illustrated in the calculations relating to the use of straight blast furnace gas in a steel reheating furnace. It is clear from that example and from Table II that the temperatures required for certain thermal processes cannot be generated without adequate preheating of either the fuel or the air, or in some instances of both. Recuperators and regenerators are then a necessity for both temperature development and fuel economy.

Heat Utilisation within a Furnace

Before the actual development of a furnace on the drawing board the designer must be able to predict its thermal characteristics with a maximum degree of accuracy. This necessitates a mathematical approach which will now be illustrated.

Let :—

H_I = Heat input to the furnace. B.T.U./hr.

H_A = Heat available for use within the heating chamber. B.T.U./hr.

H_U = Heat absorbed by the charge. B.T.U./hr.

H_W = Heat losses from the heating chamber. B.T.U./hr.

H_G = Heat content of the products of combustion at the outlet ports of the heating chamber. B.T.U./hr.

ϕ = True thermal efficiency of the heating chamber. $= \frac{H_U}{H_A} = \frac{H_U}{H_W + H_U}$

θ_F = Maximum temperature in the heating chamber. ° F.

θ_E = Temperature of the products of combustion at the outlet ports of the heating chamber. °F.

θ_{CA} = Initial temperature of the charge. ° F.

θ_{CE} = Final temperature of the charge. ° F.
W = Output of heated material. Lb./hr.
c = Mean specific heat of the heated material. B.T.U./lb./° F.
Q = Fuel consumption. Units/hr.
h_f = Nett calorific value of the fuel employed. B.T.U./unit.
h_r = Heat available from recuperation or regeneration. B.T.U./unit of fuel used.
f = A factor $= \dfrac{h_r}{w_{ga} \cdot c_{ga} \cdot \theta_E}$
w_{ga} = Weight of products of combustion per unit of fuel at θ_F. lb.
c_{ga} = Mean specific heat of the products of combustion between 60° F. and θ_F. B.T.U./lb./° F.
w_{ge} = Weight of products of combustion per unit of fuel at θ_E. Lb.
c_{ge} = Mean specific heat of the products of combustion between 60° F. and θ_E. B.T.U./lb./° F.
ψ = Pyrometric efficiency of the furnace.
η = Thermal efficiency of the furnace.

The nett hourly thermal input to a furnace is :—

$$H_I = Q\ (h_f + h_r). \qquad (1)$$

When h_r is expressed as a function of the exhaust gas temperature then :—

$$h_r = f \cdot w_{ge} \cdot c_{ge} \cdot \theta_E \qquad (2)$$

therefore $H_I = Q \cdot (h_f + f \cdot w_{ge} \cdot c_{ge} \cdot \theta_E)$. (3)

The heat available for use within the heating chamber is :

$$H_A = Q\,[h_f - (1-f) \cdot w_{ge} \cdot c_{ge} \cdot \theta_E]. \qquad (4)$$

The heat absorbed by the charge is :—

$$H_U = W \cdot c \cdot\ (\theta_{CE} - \theta_{CA})^* \qquad (5)$$

The true thermal efficiency of the heating chamber is :—

$$\phi = \frac{H_U}{H_A} = \frac{W \cdot c \cdot\ (\theta_{CE} - \theta_{CA})}{Q\,[h_f - (1-f) \cdot w_{ge} \cdot c_{ge} \cdot \theta_E]} \qquad (6)$$

The thermal efficiency of the furnace is :—

$$\eta = \frac{W \cdot c \cdot\ (\theta_{CE} - \theta_{CA})}{Q \cdot h_f} \qquad (7)$$

$$= \frac{\phi}{h_f} \cdot\ [h_f - (1-f) \cdot w_{ge} \cdot c_{ge} \cdot \theta_E]. \qquad (8)$$

$$= \frac{\phi}{h_f} \cdot \left(\frac{w_{ga} \cdot c_{ga} \cdot \theta_F}{\psi} - w_{ge} \cdot c_{ge} \cdot \theta_E \right) \qquad (9)$$

The " pyrometric efficiency " is :—

$$\psi = \frac{w_{ga} \cdot c_{ga} \cdot \theta_F}{h_f + f \cdot w_{ge} \cdot c_{ge} \cdot \theta_E} \qquad (10)$$

The hourly fuel consumption is :—

$$Q = \frac{W \cdot c \cdot\ (\theta_{CE} - \theta_{CA})}{\phi \cdot [h_f - (1-f) \cdot w_{ge} \cdot c_{ge} \cdot \theta_E]} \qquad (11)$$

Let us consider the equations in relation to the development of a continuous reheating furnace to heat steel billets from 15° C. (59° F.) to 1,250° C. (2,282° F.) at the rate of 10 tons per hour. The fuel to be used is blast furnace gas with a nett calorific value of 91·8 B.T.U./cu. ft. A temperature of 1,400° C. (2,552° F.) is required at the forehearth and the temperature of the outgoing gases must not be less than 1,075° C. (1,967° F.) when the furnace is operating at full capacity.

* Allowance to be made for any endothermic or exothermic reactions.

What will be the " pyrometric efficiency," the thermal efficiency, and the hourly fuel consumption of the furnace, to ensure a heating chamber efficiency of 80% under full load conditions when 40% of the heat in the outgoing gases is recovered for the preheating of the gas and air supplies ?

As it is essential to consider the amount of air employed for combustion and also that subsequently infiltrated, assume 10% excess air in the products of combustion at the forehearth and 20% excess in the outgoing gases.

From the data supplied it is evident that :—

h_f = 91·8 B.T.U./cu. ft.
W = 22,400 lb.
θ_{CA} = 59° F.
θ_{CE} = 2,282° F.
θ_F = 2,552° F.
θ_E = 1,967° F.
f = 0·4
ϕ = 0·8

The heat content of the products of combustion per cu. ft. of blast furnace gas is determined from Fig. 2.

At the forehearth where the gases contain 10% excess air and the temperature is 2,552° F. the heat content is :—

$$(w_{ga} \cdot c_{ga} \cdot \theta_F) = 93{\cdot}3 \text{ B.T.U.}$$

At the outlet ports where the gases contain 20% excess air and the temperature is 1,967° F. the heat content is :—

$$(w_{ge} \cdot c_{ge} \cdot \theta_E) = 68{\cdot}8 \text{ B.T.U.}$$

According to Eq. (10), the " pyrometric efficiency " of the furnace will be :—

$$\psi = \frac{93{\cdot}3}{91{\cdot}8 + (0{\cdot}4 \times 68{\cdot}8)}$$

$$= \frac{93{\cdot}3}{119{\cdot}3} = 78{\cdot}21\%$$

From Eq. (9) the nett thermal efficiency of the furnace will be :—

$$\eta = \frac{0{\cdot}8}{91{\cdot}8} \left(\frac{93{\cdot}3}{0{\cdot}7821} - 68{\cdot}8 \right)$$

$$= \frac{40{\cdot}4}{91{\cdot}8} = 44\%$$

According to Eq. (11) the hourly gas consumption will be :—

$$Q = \frac{W \cdot c \cdot (\theta_{CE} - \theta_{CA})}{0{\cdot}8 \cdot [91{\cdot}8 - (0{\cdot}6 \times 68{\cdot}8)]}$$

Now for the heating of 10 tons of steel to 1,250° C. (2,282° F.) it is evident from Table I that :—

$$W \cdot c \cdot\ (\theta_{CE} - \theta_{CA}) = 8{,}600{,}000 \text{ B.T.U.}$$

hence :—

$$Q = \frac{8{,}600{,}000}{0{\cdot}8 \times 50{\cdot}5}$$

$$= \frac{8{,}600{,}000}{40{\cdot}4}$$

$$= 212{,}800 \text{ cu. ft./hr.}$$

From the foregoing calculations the designer of the furnace can derive sufficient information to proceed with its development.

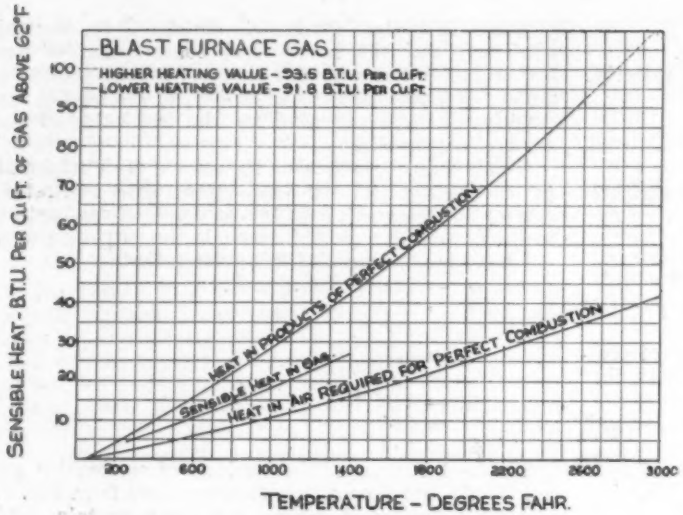

BLAST FURNACE GAS
HIGHER HEATING VALUE - 93.5 B.T.U. PER CU.FT.
LOWER HEATING VALUE - 91.8 B.T.U. PER CU.FT.
SENSIBLE HEAT - B.T.U. PER CU.FT. OF GAS ABOVE 62°F
HEAT IN PRODUCTS OF PERFECT COMBUSTION
SENSIBLE HEAT IN GAS
HEAT IN AIR REQUIRED FOR PERFECT COMBUSTION
TEMPERATURE - DEGREES FAHR.

Fig. 2.—Showing the heat content of the perfect products of combustion of a typical gas with a nett calorific value of 91·8 B.T.U./cu. ft.

For instance, the thermal distribution within the furnace, per cu. ft. of gas consumed, will be :—

	B.T.U.
(*a*) Heat transmitted to the steel .. .. =	40·40
(*b*) Thermal losses from the heating chamber =	10·10
(*c*) Heat recovered for the preheating of the gas and air supplies .. .. .. =	27·50
(*d*) Stack and flue losses, etc. .. .. .. =	41·30
$(h_r + h_f)$ .. .. =	119·30

From (*b*) it is evident that the total thermal losses from the heating chamber per hour must not exceed 212,800 × 10·1 B.T.U. = say 2,150,000 B.T.U. The chamber must, therefore, be suitably constructed to keep the losses within this limit.

From (*c*) the preheat temperature of the gas and air supplies can be determined. If the heat recovered is equally apportioned to the gas and the air then Fig. 2 shows that the respective temperature will be about 750° F. and 1,200° F. This information enables the characteristics of the recuperators to be determined in relation to the temperature of the exhaust gases.

From (*d*) and the calculated hourly gas consumption, the dimensions and characteristics of the flues, stack or exhaust fan can be determined.

It is, of course, essential for a designer to consider the thermal characteristics of a proposed furnace under different conditions of loading and operation, but the basic principle of approach has been indicated.

Finally, what is the real thermal efficiency, under full load conditions, of the furnace just considered? The efficiency based upon the relationship between the heat absorbed by the steel and that initially provided by the fuel is 44%. Due, however, to preheating of the gas and air supplies the thermal input to the furnace per cu. ft. of gas is 119·3 B.T.U. and from this only 51·4 B.T.U. are actually dissipated. Judged on the basis of heat utilisation the efficiency is consequently about 57%. This figure is low by comparison with the heat utilisation in a modern steam generating plant, but the reasons are clear to all with knowledge of the subject. It must, however, be remembered that efficient boiler plants are properly controlled, satisfactorily maintained and, as far as possible, continuously operated at or above full rating. Similar conditions are essential to the attainment of maximum thermal efficiencies in the use of industrial furnaces.

The Journal of the Iron and Steel Institute

THIS is the first opportunity we have had to welcome the above journal which began publication in its new form with the January issue. Originally published in 1869 in the form of transactions issued from time to time and later as proceedings and papers collected in a quarterly journal, which was normally bound into an annual volume, the method of publication, at the beginning, was somewhat irregular. From 1887–1945, however, a regular sequence of publication was maintained. Two volumes appeared each year and occasionally an extra volume was issued. These books are all in octavo size and very convenient to handle.

In 1939 the Council of this Institute decided on a regular monthly publication and arrangements were made to commence, but the war intervened and the project had to be shelved until 1946 when the present size of the journal (11 in. × 8¼ in.) was adopted. This will in future be standard for the technical publications of this Institute. During 1946, papers were issued each month as advance copies and abstracts of current literature were issued as a Bulletin. With the January, 1947, issue begins a new series incorporating papers, news, abstracts and book reviews.

In addition to the reports and papers of this Institute, the journal will be the normal vehicle for presenting the work of the British Iron and Steel Research Association, and it will include reports of the activities of the Iron and Steel Engineers Group. From time to time, other sections will be included, and doubtless discussion by correspondence will become a useful feature. Each monthly part will comprise approximately 150 pages of text matter—an amount not easily assimilated in so short a time between issues—and it is proposed to issue indexes and binding cases to form three volumes each year.

Members of the Iron and Steel Institute will appreciate the excellent manner in which the reports and papers are presented. The size and character of type used make reading the text a pleasure. The arrangement too makes for clarity, and editorial staff is to be complimented on the presentation of valuable work in such an able manner. We have no hesitation in welcoming this publication as one which we believe will increase the prestige of British technical publications at home and abroad. This journal especially will be of value not only to members of this Institute, but to all connected with the technical and scientific development of the iron and steel industries. The journal is free to members of the Institute, to non-members the price is 10s. per copy, which may be obtained from The Iron and Steel Institute, 4, Grosvenor Gardens, London, S.W. 1.

Correspondence

Phosphate Treatments

The Editor, METALLURGIA.

Dear Sir,

I have read with interest the communication by Mr. E. E. Halls in your December issue. In it he refers to the value of phosphate coatings as a rust inhibitor, and he mentions Coslett's name as one of the pioneers. At the same time he enlarges considerably upon the development work which has been undertaken in recent years by the Parker Rustproofing Corporation of America, the Pyrene Co. Ltd., and the I.C.I. Granodising process. He is careful to point out that Rovaline and Walterisation are newer processes and develops his argument that the knowledge which has been acquired from many years of development and application is not easy to attain in a short time with the very thinly disguised implication that the latter processes thereby suffer in comparison with the former for this very reason.

As far as the scientific considerations of phosphating are concerned, there have indeed been very few British publications on the subject. Holden (J. Electrodepos. Tech. Soc., 1944, 19, 2 –34) outlines some very important points regarding the chemical and electrochemical factors which influence the formation of phosphate coatings. However, it has been left to German chemists to outline the scientific reasoning behind the value of phosphate coatings.

In particular Macchia has contributed some original findings on the ratio of the combined to free phosphoric acid and the influence of concentration on both the time and protective value of phosphate coatings. Machu has contributed some interesting original work on the efficiency of different accelerators in phosphating baths; one of the most important findings being that in an accelerated bath the cessation of hydrogen evolution does not indicate the end point of the process. With accelerators such as potassium dichromate, sodium bisulphite, copper carbonate and quinoline in a Parker bath the end point of the process so determined by cessation of hydrogen was respectively 4·5, 13, 3 and 10 minutes. When, however, the end point was determined by an estimation of the free pore space or by examining the change in potential of an iron electrode which was undergoing phosphate treatment ; the times for these respective processes were as follows :—

Pore space measurements : 40, 20, 10 and 13 min.

Potential measurements : 40, 35, 10 and 22 minutes.

It is, therefore, wrong to imagine that the true chemistry of the phosphating process is in any way a closed book. The German references together with some very interesting published work by Russian investigators, form a basis from which any chemist can enter the business with very reasonable hopes of success.

Furthermore, when comparisons are made between old and new processes, it should be borne in mind that when an organisation builds up a process, its growth, structure, its commercial relationships and the economic aspects of manufacture do sometimes tend to prevent new modifications being introduced, because they interfere with the continuity of supplies and organisation which is already established.

During the war it was the newer Rovaline process which was finally adopted by one of the larger Ordnance Factories for the treatment of high tensile steels. As is known, this is a particularly difficult problem, because normal phosphating solutions often give a very poor key to highly polished or high tensile steels. In fact, during Bren gun barrel manufacture it had been the practice to phosphatise the component and then remove the phosphate layer from the interior of the barrel by the simple procedure of pulling through a piece of cloth on the end of a wire. When the newer Rovaline process was employed it was found impossible to do this, whilst one of the hardened steel sights from a Bren gun, which was phosphated by the Rovaline process, is still available and demonstrates quite clearly the tenacity with which the phosphate film adheres to high tensile steel.

My main reason for drawing your readers' attention to these points is to confute the implication which may be obtained from Mr. Halls' communication that a newer process, of which he quotes examples of Rovaline and Walterisation, may necessarily be handicapped in comparison with older established processes, of which he quotes Parkerising and Granodising. After all, these newer processes did have an ample opportunity to establish themselves during the war years, and in that period contributed some very valuable results.

Lockfield Avenue,
Enfield,
Middlesex.
January 17th, 1947.

Yours faithfully,
International Corrodeless, Ltd.
W. F. COXON,
Technical Adviser.

The Editor, METALLURGIA.

Dear Sir,

I have carefully studied Dr. Coxon's letter which comments upon and complements my communication in your December issue.

It is true that much work has been done in Germany on this subject, and fine as the majority of this may have been, I have not seen any evidence, on the practical side, that the efficiency of phosphate processes in Germany approaches that in America or in this country. This refers to the rapidity and cost of processing, efficiency of the coating when applied, and to the breadth of the field of exploitation, including "design for phosphatising."

I feel that Dr. Coxon has misread my communication in one or two important aspects. I very much regret this and if other readers have been led to do the same, I urge them to re-read and consider it. I should like to take this opportunity of stressing a few points—viz. :—

1. The remarkable advances achieved in the last 10–20 years, culminating in speed of processing with quality of finish are not the last word. This was stated in the last sentence on page 69 of my communication.

2. On page 70, admittedly I referred to the Rovaline and Walterisation treatments as "much newer" than the Parker and Granodising processes (a statement I believed to be true), but I bracketed all these together as established processes from which to start.

3. I am convinced that the success of any phosphate process is not solely determined by the development of the correct solution formula (which, of course, is essential), but also by providing a simple method for chemical control and for correcting the solution as indicated by this control. I particularly urge that this aspect should not be overlooked when contemplating changes from any of the established processes.

I feel very perturbed at causing Dr. Coxon to obtain

wrong impressions from my communication. From experience with work finished by his Company's processes—Rovaline, Spraylene, Electrolene—and with "Walterised" goods—there was certainly no suggestion of belittlement in my thoughts. I trust that a second reading of the publication will enable him to unreservedly change his views.

Greenhill Park, New Barnet, Herts. January 23rd, 1947.

Yours sincerely, E. E. HALLS.

Cohesive Strength and the Creep of Copper and Monel

The Editor, METALLURGIA.

Dear Sir,

In the December, 1946, issue of METALLURGIA, E. Voce gives a review of the literature on "Copper and Copper Alloys" for 1946. His discussion of the paper by D. J. McAdam, Jr., G. W. Geil, and D. H. Woodard contains several statements that may tend to give an incorrect impression. The first of these statements is, "For a number of years McAdam has championed the use of the 'technical cohesive strength' of metals as a criterion of the deformation which the material will endure before fracture." The technical cohesive strength is merely the resistance to fracture expressed in terms of the same units that are used to express the resistance of a metal to flow. Our work has shown that the technical cohesive strength cannot be expressed in terms of a single stress value but comprises an infinite number of technical cohesion limits, each corresponding to a specific combination of the three principal stresses. I certainly have not "championed" resistance to fracture as a criterion for ductility.

Dr. Voce apparently holds to the old idea that the term "technical cohesive strength" applies only to the stress necessary for fracture under polysymmetric tension. After presenting this view and referring to the use of notched specimens in investigations of technical cohesive strength, he says: "In this latest paper, McAdam and his collaborators apply such considerations to annealed and to cold-worked copper and monel metal." The paper reviewed, however, is confined entirely to determinations of the cohesion limits for unidirectional loading of unnotched specimens. No consideration, either in text or diagram, is given to the cohesion limit for polysymmetric tension (disruptive stress). The only metals used in the creep tests were cold-worked monel metal and copper, and the temperature ranges were above room temperature. In this investigation a study was made of the actual relations between cohesion limit, flow stress and ductility. Results of low temperature tests reported in previous papers were included in four of the thirty-three figures. The lowest temperature considered, however, was that of liquid air (–188° C.), which is not "near absolute zero."

Dr. Voce also says: "It is unfortunate that straightforward extension-time curves are omitted." Five extension-time curves were included in the paper. As load-changes were made during the experiments, possibly the word "straightforward" was used to signify "conventional." No apology appears necessary for unconventionality in scientific work.

Yours truly, D. J. MCADAM, JR.,
Chief, Thermal Metallurgy Section,
Division of Metallurgy.

National Bureau of Standards,
Washington, U.S.A. January 24th, 1947.

The Editor, METALLURGIA.

Dear Sir,

The conception of technical cohesive strength, as developed by Dr. McAdam and his collaborators in a long series of papers, is by no means an easy one to comprehend. My main object in including a review of his recent paper was to present as succinctly as possible the basic principles underlying the whole of the work in terms which could readily be understood.

Dr. McAdam appears to accept the explanation which I gave of the relationship between polysymmetric cohesive strength, yield point and degree of cold work. On this basis the cohesive strength must be regarded as a major factor governing the degree of cold work which the material will withstand without fracture—i.e., its essential ductility. Similarly, if I understand Dr. McAdam correctly, the cohesion limit under unidirectional loading is the true stress required to initiate "progressive fracture" under given conditions of strain rate, temperature, etc. Because true stress depends on deformation, this cohesion limit also is closely related to the deformation which the material will withstand without incipient failure—i.e., to its essential ductility under the given conditions. Perhaps my use of the word "criterion" was a little inapt to express this relationship, which Dr. McAdam discusses ("champions") at considerable length in several papers including the one under review.

Far from "holding to the old idea that the term technical cohesive strength applies only to the stress necessary for fracture under polysymmetric tension," I do not "hold to" any of Dr. McAdam's ideas at all, but have merely tried to indicate them in their very simplest form. Realising that the particular paper under discussion was not concerned with polysymmetric tension, but with the allied cohesion limit for unidirectional loading, and lacking space to embark on a description of the latter with its added complications of the effect of strain rate, etc., I was careful to say that Dr. McAdam had "applied *such* considerations," not "*these* considerations" to copper and Monel metal.

On page 2 of the paper under discussion, the authors state categorically that "the metals were tested both in the cold-worked and annealed conditions"; and in Table II they present the annealing treatment used. Fig. 29 is headed, "Copper N and N–8" while Figs. 30 and 31 refer to "Monel metal G and G–14." According to Tables I and II these indicate both the cold-worked and the annealed conditions. I submit that Dr. McAdam has overlooked this when he says that only the cold-worked metals were used, though the creep data presented in the paper are certainly confined to the cold-worked materials.

The curves given in Figs. 29 and 31 commence at 80° K.; how "near" this is to the aboslute zero is a matter of opinion. There is no indication that the curves would do other than extend almost linearly to the absolute zero.

I should have said, "it is unfortunate that straightforward (i.e., conventional) extension-time curves *for copper* are omitted." All those given in the paper refer to Monel metal which, being a nickel, rather than a copper-base alloy, is a little outside the scope of my review. Orthodox creep curves for the copper would

Continued on page 238

The Development of a High Creep Strength Austenitic Steel for Gas Turbines

By D. A. Oliver, M.Sc., and G. T. Harris, M.A.

Research Department, William Jessop & Sons, Ltd.

The conception of the gas turbine is not of recent origin, but its development awaited the advent of suitable materials, strong and non-scaling for operation at temperatures of about 650° C. and over. The early history has been recorded by Whittle[1] and different aspects of what might be described as the first stage of the work have been amplified in a Symposium[2] of papers. These cover the ground up to about 1943. Just before this time the authors of the above paper, presented at a recent meeting of the West of Scotland Iron and Steel Institute, became intimately involved with turbine disc and blade problems and some of their work is described particularly that on the development of G. 18B with which this paper is largely concerned and from which the present article has been abstracted.

FOR some years prior to 1943 investigations had been in progress in the Research Department of William Jessop & Sons, Ltd., with the broad objective of evolving a stronger austenitic valve steel than the type represented by specification D.T.D. 49B. These had involved providing creep-testing equipment capable of operating continuously at temperatures up to 900° C., and this equipment was highly suitable for testing gas turbine materials when the need arose. In fact, the early fundamental work on the austenitic valve steel G. 2, which conformed to D.T.D. 49B, provided just the right kind of background, and with only one intermediate stage led directly to the development of G. 18B, with which this paper is largely concerned.

Early Developments

The first experiments carried out on the creep strength of alloys were on various austenitic steels, in particular G. 2 steel and certain small modifications of it. A testing temperature of 800° C. was employed as standard in these early sorting tests, together with an applied stress of 5 tons/sq. in. The compositions of the steels tested are given in Table I. Results of the tests showed a very large variation in creep strength and indicated that many factors needed investigation, particularly the effect on creep strength of small quantities of certain elements. The steel F (the valve steel G 2) with titanium (H) or with aluminium (J) additions, showed much lower creep rates. Their rupture strengths, however, were not high, due to lack of ductility. In following up these variables, casts of F and J compositions were made in a 100-lb. high-frequency furnace, and it was found that melting and casting practice had also a large effect on creep strength.

This work, which formed part of a long-term research plan, became important in connection with materials for the blading of jet propulsion gas turbines. The requirement then defined was that a stress of 12 tons/sq. in. at 650° C. should produce a deformation in creep not exceeding 0·1%. Accordingly, the sorting tests were changed and a considerable number of experimental melts were made and tested in an endeavour to meet the new requirement. Most of the austenitic steels tested at that time had given lives that scarcely reached 300 hours. For instance, G. 2, which was one of the strongest, gave a life of 350 hours, and a strain of 11% at 300 hours. However, the various steels which had been given a solution treatment of the order of 1,250° C. gave strains in the range 0·2–1·0%. Unfortunately, with reasonable creep strength they showed low ductility. It was found, however, that this property could be appreciably increased by lowering the chromium content, and G. 17 was launched. This steel gave appreciable creep strength, but it was associated with low ductility. The microstructure of this steel revealed that the grain boundaries were all outlined by a film of carbides which was believed to be the cause of both strength and lack of ductility.

Experiments were put in hand to increase the ductility of these steels by various additions. Earlier investigations on the G. 2 steel had shown that a drop in impact value after long soaking times at temperatures of about 650° C. could be best avoided by additions to the steel of niobium. Alternatives in use were molybdenum,

TABLE I.—Compositions of Early Austenitic Steels: Weight %

	A	B	C	D	E	F	G	H	J
Carbon	0·5	0·5	0·15	0·9	0·5	0·5	0·45	0·45	0·5
Manganese ..	0·8	1·2	0·8	0·7	0·8	0·7	0·8	0·7	1·1
Silicon	2·2	2·4	1·1	1·5	1·6	1·3	1·4	1·3	1·7
Nickel	32·9	34·6	10·2	10·0	13·1	13·2	13·5	13·4	13·1
Chromium ..	14·7	14·4	18·4	18·7	12·6	13·0	12·7	13·4	11·7
Tungsten ..	3·8	3·6	—	—	2·4	2·5	2·5	2·2	2·3
Molybdenum	—	—	2·0	2·1	2·0	0·1	0·1	0·1	—
Niobium ..	—	—	—	—	—	—	0·14	—	—
Titanium ..	—	—	0·5	—	—	—	—	0·04	—
Vanadium ..	—	—	—	1·8	—	—	—	—	—
Aluminium ..	—	2·0	—	—	—	—	—	—	1·1

TABLE II.—Embrittlement Tests on G.2 Valve Steel (D.T.D. 49B).
(Initial impact tests were made after normalising from 950° C)

Addition	Izod Impact: ft. lb.				
	Initial Value	After 300 hours at 650° C.	Drop %	After 600 hours at 650° C.	Drop %
Nil	28	15	46	—	—
Nil	40	21	48	—	—
Nil	46	18	60	—	—
0·20% Ti	42	39	7	—	—
0·5% Mo +0·10% Ti	32	30	7	—	—
0·5% Mo + 0·43% V	25	23	8	19	24
0·5% Mo + 0·43% V	26	23	12	20	23
0·11% Nb	44	40	9	38	14
0·12% Nb	32	30	7	28	13

1 "The Early History of the Whittle Jet Propulsion Gas Turbine," by F. Whittle. Proc. Inst. Mech. Engrs., 1945, vol. 152, p. 419.

2 Symposium on "The Development of the Internal Combustion Turbine." Proc. Inst. Mech. Engrs., 1945, vol. 153, p. 409.

titanium or vanadium, sometimes in combination. It was ultimately found that the addition of approximately 0·15% of niobium proved satisfactory for decreasing this embrittling tendency. The results of some of the tests carried out in confirmation are reproduced in Table II. The striking effect of such a low percentage addition of niobium as 0·12% in practically eliminating embrittlement, suggested experiments with higher percentages, with the object of conferring higher ductility under creep-testing conditions. Accordingly, steels containing various additions up to 3% niobium were tested and proved successful. Other experiments explored the influence of cobalt and finally a steel containing 10% of cobalt was fully developed and became with slight modifications G. 18B.

G. 18B Steel

The composition of G. 18B is reproduced in Table III with that for WEX 298, which was similar, but without cobalt. It will be noted that G. 18B is essentially a carbon-bearing austenitic steel containing nickel, chromium and cobalt, with additions of three strong carbide forming elements, namely, tungsten, molybdenum and niobium.

TABLE III.—Composition and Heat-treatment of Eight Austenitic Steels (*Composition in weight %*).

Element	G.2	R.16	R.18	R.20	WEX 299	G.17	WEX 298	G.18B
Carbon ..	0·4	0·1	0·3	0·14	0·33	0·4	0·4	0·4
Manganese	0·7	0·8	0·5	0·8	0·8	0·8	0·9	0·8
Silicon ..	1·3	1·2	1·7	0·4	2·3	1·5	1·5	1·0
Nickel ..	13·0	9·5	7·5	14·0	25·7	25·0	13·7	13·0
Chromium	13·0	18·5	19·0	19·0	22·2	13·0	14·3	13·0
Cobalt ..	—	—	—	—	—	—	—	10·0
Tungsten ..	2·5	—	3·5	—	2·0	2·5	2·5	2·5
Molybdenum	—	—	—	—	1·8	2·0	1·9	2·0
Niobium ..	0·15	—	—	1·7	—	—	2·9	3·0
Titanium ..	—	0·7	—	—	—	—	—	—
Heat-treatment	Normalised 950°C	Normalised 1039°C	Normalised 950°C	Normalised 1100°C	Oil-Quenched 1280°C	Oil-Quenched 1275°C	Oil-Quenched 1300°C	Normalised 1300°C

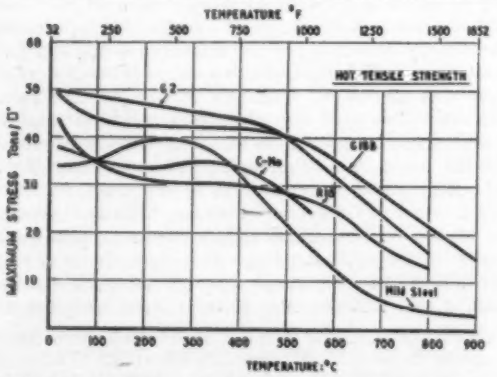


Fig. 1.—Hot tensile strengths of various steels.

Initially the heat-treatment of this steel was a solution heat-treatment at approximately 1,330° C. followed by oil quenching or air cooling. The creep strength did not appear to be greatly dependent upon the rate of cooling and usually oil quenching was only applied to large forgings to minimise scaling during the lengthy cooling from the temperature of solution treatment. The properties as solution treated included a high-creep strength but comparatively low proof stress. It was found possible to raise the 0·1% proof stress from 13 to about 18 tons/sq. in. by imposing an ageing treatment of

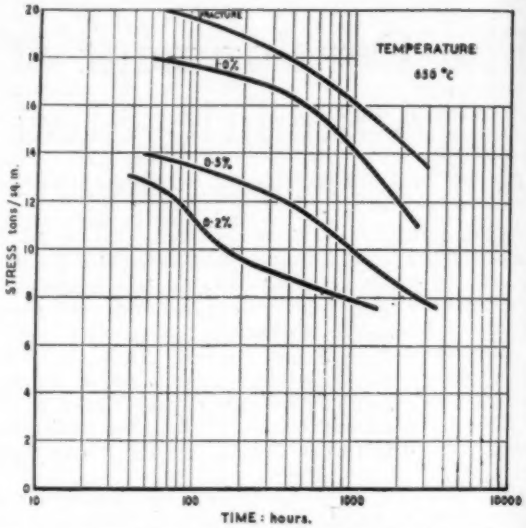


Fig. 2.—Stress/time curves for stated creep strains of G. 18B steel at 650° C.

20 hours at 800° C. This ageing treatment was found to decrease the creep strength a little. It was desirable to raise the proof stress still more without sacrifice of creep strength, and this was accomplished by a process which the authors refer to as " warm working." This process consists in subjecting the steel, after it has been solution heat-treated to about 1,300° C. to plastic deformation at a temperature in the range 650°–800° C. By this method it has been found possible to increase the 0·1% proof stress at room temperature to about 25–30 tons/sq. in. Normally this is not attended by any decrease in creep strength, as after ageing; in many cases an increase in creep strength occurs, in fact, under certain controlled conditions the creep strength can be raised very considerably by warm working.

In addition to mechanical properties, the gas turbine designer requires various physical constants, particularly for the calculation of thermal stresses. Table IV

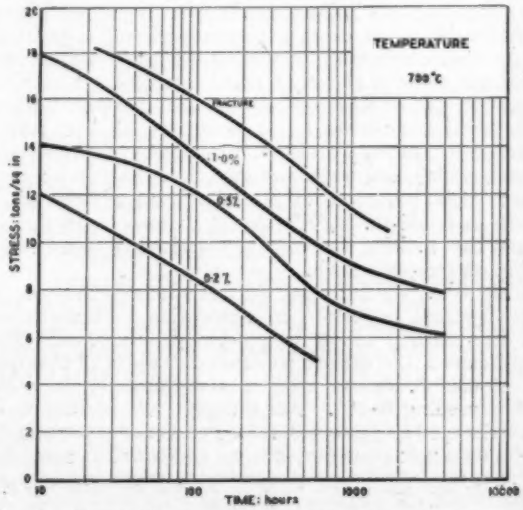


Fig. 3.—Stress/time curves for stated creep strains of G. 18B steel at 700° C.

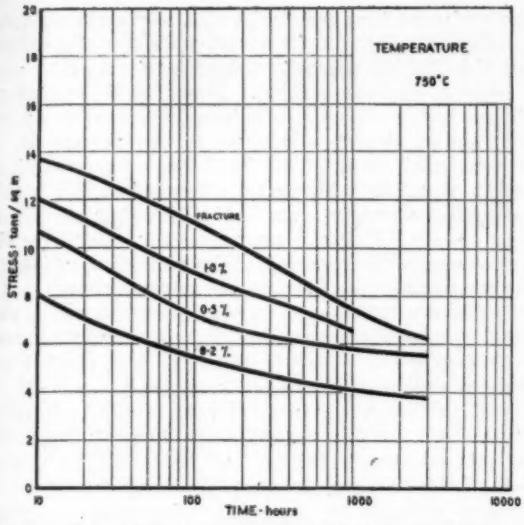


Fig. 4.—Stress/time curves for stated creep strains of G. 18B steel at 750° C.

summarises the physical properties most often required up to a temperature of 900° C. The mechanical properties at room temperature are given in Table V, together with those obtained in the aged condition (20 hours at 800° C.), and those obtained from warm worked dice forgings of about 18 in. in diameter.

The variations of the tensile strength with temperature of G. 18B steel and certain other steels are reproduced in Fig. 1. The values for mild steel and for the 0·5% molybdenum steel, widely used for creep resistance at steam temperatures, are included for comparison purposes together with 18–8 stainless steel stabilised with 0·5% titanium (R. 16), and the austenitic valve steel G. 2. Hot tensile strength tests, however, are not very discriminating between different high temperature materials, and wide variations in creep strength can occur in these steels without appreciably affecting hot tensile results. In the tests recorded in Fig. 1, a rate of strain of 0·028 per min. was used.

TABLE IV.—Physical Constants of G. 18B Steel

Temperature °C.	Density gms./cc.	Density lb./cu.in.	Mean Linear Thermal Expansion Coefficient (20° C.–θ° C.) per °C.	Thermal Conductivity c.g.s. units	Young's Modulus tons/sq. in.
20	$8{\cdot}1_8$	0·294	—	—	13,500
100	$8{\cdot}1_6$	0·293	$15{\cdot}6 \times 10^{-6}$	$0{\cdot}03_2$	13,300
200	$8{\cdot}0_7$	0·292	$15{\cdot}8 \times 10^{-6}$	$0{\cdot}03_8$	13,000
300	$8{\cdot}0_2$	0·290	$16{\cdot}5 \times 10^{-6}$	$0{\cdot}04_1$	12,600
400	$7{\cdot}9_8$	0·289	$16{\cdot}9 \times 10^{-6}$	$0{\cdot}04_4$	12,000
500	$7{\cdot}9_4$	0·287	$17{\cdot}1 \times 10^{-6}$	$0{\cdot}04_9$	11,400
600	$7{\cdot}9_0$	0·286	$17{\cdot}3 \times 10^{-6}$	$0{\cdot}05_2$	10,600
700	$7{\cdot}8_5$	0·284	$17{\cdot}7 \times 10^{-6}$	$0{\cdot}05_7$	9,800
800	$7{\cdot}8_0$	0·282	$18{\cdot}0 \times 10^{-6}$	$0{\cdot}06_1$	9,100
900	$7{\cdot}7_5$	0·280	$18{\cdot}3 \times 10^{-6}$	$0{\cdot}06_5$	—

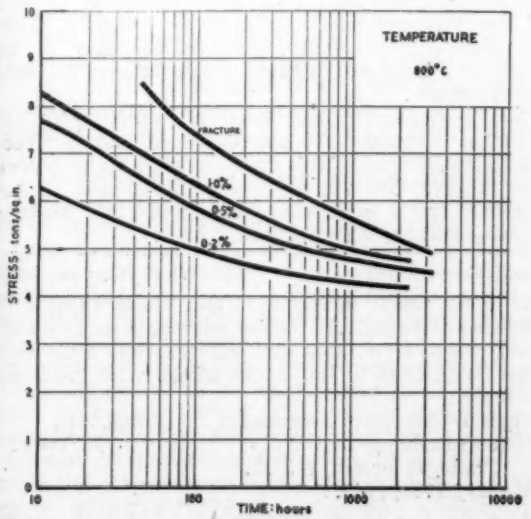


Fig. 5.—Stress/time curves for stated creep strains of G. 18B steel at 800° C.

TABLE V.—Mechanical Properties at Room Temperatures.

	Solution Treated	Solution Treated and Aged	Warm Worked Disc Material
0·05% Proof Stress tons/sq. in.	12·5	15	24
0·10% Proof Stress tons/sq in.	14	18	25
0·20% Proof Stress tons/sq. in.	17	21	28
0·50% Proof Stress tons/sq. in.	20	25	31
Maximum Stress tons/sq. in. ..	46	48	48
Elongation on $L = 4\sqrt{A}$ % ..	40	25	12
Reduction of Area: %	45	22	15
Izod Impact ft. lb.	50	—	—
Fatigue Limit tons/sq. in. ..	±23	—	—

Creep data for G. 18B are given in Figs. 2, 3, 4 and 5 for specific temperatures between 650° and 800° C. These curves enable the designer, when he has specified the total permissible strain and the working life, to ascertain for specific temperatures what stress can be applied. For instance, for a strain of 1·0% in 3,000 hours at 700° C., Fig. 3 indicates a stress of 8 tons/sq. in. This method of presenting data as will be realised from the fact that a set of curves summarises the results of about 20 long-time creep tests.

In addition to creep strength the designer requires, especially for turbine blade work, the fatigue strength at high temperatures, both with zero mean stress and with a superimposed tensile stress. The second condition

TABLE VI.—Hot Fatigue Data on G. 18B Steel: S.T. 1300° C.

Temperature °C.	Endurance Limit (Zero Mean Stress) tons/sq. in.	Endurance Limit (Tensile Mean Stress) tons/sq. in.
600	±18	20 ± 8·5
650	±15	14 ± 10·0
700	±13	12 ± 8·4
750	±10	9 ± 8·7
800	± 8·5	6 ± 5·7

corresponds to a blade having a centrifugal tensile stress and a superimposed bending stress due to the pulsating gas stream passing through the nozzle ring. Test results obtained under these conditions are reproduced in Table VI; they are expressed in the form X ± Y tons/sq. in., where X is the applied steady tensile stress and Y the medium fluctuating stress which can be superimposed without causing fatigue failure in 40 million reversals of stress during 300 hours continuous testing.

Future Trends

Assessing G. 18B steel in the light of the considerations outlined in this paper, it has been found for most design purposes to possess adequate creep-, fatigue-, and

impact strengths at high temperature, with freedom from non-metallic inclusions and other metallurgical stress-raisers. The proof stress between room temperature and 500° C. is low, like most austenitic steels. Even the value of 25 tons/sq. in. for 0·1% strain obtained by warm-working could be raised with advantage in future developments. The tendency to embrittlement under the simultaneous influences of stress and temperature does not appear to be sufficient to cause undue concern.

The manufacturing difficulties in producing sound ingots with the subsequent forging and manipulation have been largely overcome in the light of accumulating experience from attempting to produce progressively larger forgings.

In the light of the above it can be concluded that the particular austenitic steel under discussion can claim a wide field of usefulness. The presence of adequate ductility and toughness associated with a high-creep strength meets normal engineering demands. It is obvious that greater creep and fatigue strengths, a higher proof stress, and greater scaling resistance, without sacrifice in ductility and toughness, are the directions in which future developments may be expected to occur. However, it is one thing to achieve a small-scale laboratory result and another to succeed in manipulating ingots of many tons in a steel works. General considerations indicate the need for a complete range of economic materials having adequate properties for specific components in the gas turbine. Better steels and alloys will surely become available during the next few years and some are already well advanced in development. A new austenitic steel (G. 32) having a creep strength at 750° C. about 75% higher than that of G. 18B is now undergoing exhaustive examination. Preliminary indications are that it should prove specially useful for the early stages of the rotating blades which are subject to onerous conditions of stress and temperature.

During the next few years greater attention may also be expected to be devoted to the general study of steels and alloys over extended periods of test so that gas turbines designed to operate successfully for a life of several years may have uncertainties reduced to a minimum. New creep laboratories are being equipped and old ones are being extended, but few realise the magnitude of the task lying ahead, if the engineer is to be supplied with all the essential information. A start has been made, and it is hoped that Great Britain will continue to maintain her lead in this fascinating field of high temperature research.

Obituary

Dr. A. H. Jay

It is with great regret that we announce the death of Dr. A. H. Jay, at the early age of 40, as a result of head injuries received in a car accident caused by the extreme weather conditions recently experienced. His death is a great loss to the world of science and particularly to the Central Research Department of the United Steel Companies, which he joined in 1933 with a very enthusiastic recommendation from Prof. W. L. Bragg. He was a valued member of the Metal Physics Committee of the British Iron & Steel Research Association.

As stated in an appreciation written by his friend and colleague, Dr. J. H. Chesters, Dr. Jay possessed a rare combination of gifts. Although a pure scientist of very high standing he could talk to anyone in the steelworks in their own language. He had a passion for accuracy, yet never allowed himself to be confused by detail. His reaction to any problem was always stimulating and, for this reason, his close contact with the various sections of the Research and Development Department of The United Steel Companies, Ltd., was always welcomed. Whilst his own peculiar field was X-ray analysis, he made an equal contribution in the field of refractories and notable contributions to various aspects of metallurgical work. During the few years prior to his death, he went a long way towards placing the understanding of steelmaking on a simple scientific basis and was obtaining particularly exciting results on the fundamentals of creep strength at the time of the accident.

His work with the United Steel Companies was of outstanding quality. He gave a new slant to every problem he handled and valuable assistance to many workers outside his own immediate field. His superb technique was well illustrated by his work on the stabilisation of dolomite bricks and the constitution of sea-water magnesia. It was his X-ray analysis of a number of "perished' dolomite bricks that gave the clue as to the real cause of failure and pointed the way to the stabilised dolomite brick as we know it today. His initial X-ray survey of the field of refractories has long since been accepted as a standard.

His loss will be most felt by his wife and five-year-old daughter, but will continue to be felt for many years by his colleagues in the Research and Development Department, not so much because of his extraordinary genius but because of the "happy warrior" attitude which he brought to every situation, whether it was a difficult technical problem or a departmental cricket match.

Mr. James Foster-Smith

It is with deep regret that we have to announce the death on January 24th, 1947, of the Managing Director of The Wellman Smith Owen Engineering Co., Ltd., Mr. James Foster-Smith, who passed away at his residence, "Kenton," Hillcrest Road, Ealing, W., after a short illness.

Mr. Foster-Smith had been associated with the Wellman Companies for over 40 years, and had been Managing Director of this Company since its incorporation in 1919. He will be greatly missed and his loss mourned by a large circle of friends and business associates at home and abroad.

Correspondence *Continued from page 234*

have been useful to engineers and others engaged in problems of design. All too few creep data are available, and it seems a pity that such curves, which must have been determined in the course of the work, were not presented.

Copper Development Association, Yours, etc.,
Grand Buildings, E. Voce.
Trafalgar Square, W.C. 2.
February 17th, 1947.

Much correspondence has unavoidably been held over for publication in our April issue. Ed.

The Infra-Red Gas Burner*

By L. Sanderson

Some examples of actual infra-red burner applications are given to show how widely this process can be adopted industrially.

THE question is sometimes asked whether existing plant can be converted to infra-red principles. The answer is that this is perfectly possible, and costs much less than putting down an entirely new plant Incidentally, it should be noted that the modern burner can work in vertical, horizontal, inverted or other positions. Some examples of actual infra-red burner application may now be given to show how widely this process is being adopted industrially.

Heating Ester Kettles

In one large varnish works, infra-red burners are being employed as a means of heating the large ester kettles. The plant is so constructed that it operates on a succession of five operations to permit of close control over a maximum input of 2,520,000 B.th.u's/hr. The burners are grouped about a pair of circular type manifolds. Those on the outer manifold are used for bringing the heat up to the desired temperature; the inner burners maintain the temperature. Starting from cold, all burners function at maximum output. As they approximate to the requisite temperature, the outer burners turn down on low, whereas the inner burners do not change. As soon as the desired temperature is attained, the outer burners turn off, and the inner burners are left to function on a high-low basis in order to keep up the temperature. If the temperature is exceeded at any moment, the inner burners at once turn off, while if for any reason the temperature falls suddenly, the outer burners turn on again. Thus, strict control over an extensive temperature range is obtained.

Drying Paints and Varnishes

Short-cycle drying of every kind of paint and varnish is another wide field of use for the infra-red gas burner, and it is advantageously employed with a recirculated air system. This is designed to keep the temperature uniform throughout the drying stove, and to prevent the creation of regions of high temperature directly above the burners. By these means the oven is kept clean in the sense that the atmosphere within it is periodically and frequently changed. In one such system 120 complete changes of air per hour are achieved, together with an extra 9,000 cu. ft. of air exhausted per gallon of thinner or reducer employed in production. Moreover, the volatile vapours inside the stove are maintained at a temperature well below the ignition point, which means less risk of explosion or fire.

Proportionate volumes of clean air are automatically fed into the system to balance the supply. Adjustable louvres in the pressure and exhaust ducts facilitate the maintenance of uniform temperature over the entire stove irrespective of the dimensions or form of stove in use. The placing of the burners is such that all surfaces of the work are subjected to the greatest possible radiation.

Browning Pastries

Infra-red gas burners are also being installed in large baking ovens mainly devoted to the browning of pie-tops and other pastries. Here the burners are employed in the inverted position, and by reason of the strict control and uniform infra-red radiation achieved, as well as the fact that there are no concentrations of heat, the foods are given an excellent browning whatever their situation in the oven. It is claimed in food processing that use of the infra-red burner gives a greater rate of output, a uniform finish easily controllable, and a better flavour, when used for cooking, baking or roasting such foods as meats, bread, coffee, etc. In addition a saving in fuel is claimed.

Infra-red burners are also being used in the roasting chambers of coffee and monkey-nut roasters, where higher output together with better quality is claimed. In smoke houses, these burners also render possible a considerable economy in fuel, while producing less shrinkage and a stricter control of the processing atmosphere.

Annealing Springs and Shells

An up-to-date employment for the infra-red gas burner is in the annealing of springs, shells, housings, etc. The shells are annealed in a small continuous furnace through which passes a conveyor loaded with the parts. The burners fire down from the arch of the furnace in such a way as to make the furnace chamber virtually a burner in itself. The effect is to control the furnace atmosphere and minimise oxidation of the surface of the material being annealed.

Because the burners are placed inside the furnace, the correct annealing temperature is attained much faster, while the atmosphere is brought to the right condition more quickly. Fuel expense is minimised and output increased. The burners can, as earlier indicated, be employed in any position. This renders them equally suitable for such work as locally heat-treating shell noses, or for use in large furnaces designed to heat up steel plates, in which an even heating of the whole surface of the plate is essential.

A further interesting application is to booster units to facilitate the first increase of temperature. To run briefly through other industrial applications, one may mention the finishing of bumper brackets given an asphalt black oil finish and annealed at temperatures ranging from 60°–450° C., which takes from 9–15 mins. The baking of lithographed syrup tins; giving an olive coloured prime finish to scouting car springs, taking from 4–7 mins.; case drying drab olive finishes on steel, needing 5–10 mins.; drying the finishes of radio parts, which takes from 7–15 mins.; cooking sweets in jacketed pans; smelting soft metal, where the advantage lies in the longer service life of the pots; heating stereotype kettles, which gives a closer control of temperature;

* Continued from page 189, February issue.

and evaporating moisture from a large wooden oven measuring 155 ft. in length.

The Capacities of Infra-red Burners

In determining whether or not infra-red gas burners represent an economical unit for a particular application, it is essential to know the gas consumption of the burner. This is decided by the effective surface combustion area of the combustion bowl, in a burner of the type described in the previous article. It has been demonstrated that all gases can be burned equally effectively in these burners whatever their heating value, and that the B.th.u. rated consumption for a specific burner does not vary whatever the type of gas combusted.

Every standard size of burner is, for this reason, rated in B.th.u. capacity, and Table I gives a list of these capacities, based on a typical burner of the kind previously described. It must be noted, however, in using this table that the opening of the baffle—i.e., the burner port opening or orifice, and the manifold pressure necessary for the number of B.th.u's passing through, depends to some degree on the type of gas combusted, and on the volume of surplus air delivered with the gas. It is not essential to the full oxidation of the gas that surplus air should be delivered, but the common custom is to allow for 10% of surplus air when calculating the rated capacities.

It does not follow that the infra-red burner will only function at its rated capacity, though naturally it will function best at this capacity. It can be operated either above or below the rated capacity by reducing or increasing the baffle opening. If the gases used differ from that on which Table I is based, then a correction factor must be applied. The writer will gladly give these correction factors in tabular form if desired.

If for any reason a burner is used at a capacity less than 50% of its rated value, there will be found a marked decline in the efficiency of the burner. Should the burners be located in a sufficiently narrow and heat-retaining firebox, the decline in temperature and in radiant energy will be less obvious than in ordinary cool air. Turndown is not, however, impossible at this low capacity, nor is it necessarily true that full combustion cannot be attained. All that happens is that the relative proportion of radiant energy set free to available energy as B.th.u's in the fuel becomes rather less. There will be a greater proportion of heat given off in the form of hot gases.

Operating Above Capacity

If a burner is caused to function at a capacity in excess of its rating, the net effect is the formation of a border of flame around the edge of the combustion bowl. Complete combustion is not prevented, but a proportion of gas is burned at a point where it is not transformed into radiant energy.

Burners should never be allowed to operate with baffle openings less than those specified by the maker of the burners for the particular size of burner used. If this is done, the result will be an insufficiently radiant surface of the combustion bowl and a streaky type of combustion. The trouble cannot be remedied by modification of the manifold pressure. Combustion will still be complete, but there will be less radiant energy brought into play.

On the other hand, baffle openings in excess of those specified by the burner maker produce an unstable flame, together with too dense a gas-air mixture. If the right quantity of mixture for the burner capacity cannot be passed through without excessive baffle opening, the maker should be consulted.

Too little air is bad practice, unless for some reason a reducing atmosphere is required. The gas-air proportion should indicate no lack or surplus of air as compared with the volume required to ensure total combustion of the fuel. When burning manufactured gas with a high percentage of H_2, the propagation speed is too great to enable the operator to carry out the minimum and maximum adjustments standardised by makers in their tables. If the manifold pressure is below 2 in. W.C., there may be excessive flashback. Baffle turns may be reduced and manifold pressures increased to control input, but raising the baffle will be found to cause a reduction in the velocity of discharge, and will, therefore, similarly lead to flashback. H_2 is often present in high proportions in the gases of the lower B.th.u./cu. ft. class, ranging up to 650 B.th.u./cu. ft.

TABLE I.

Burner Dimensions In.	Rated Capacity B.th.u./hr.	Baffle Setting	Capacity Range B.th.u./hr.	Range of Baffle Settings
2½ dia.	10,000	3½	7,150–11,400	2½–4
3½ „	22,000	3½	15,700–25,100	2½–4
4½ „	36,000	3½	25,700–41,200	2½–4
6½ „	65,000	1½	43,400–86,600	1–2
8½ „	93,000	1½	76,000–152,000	1–2
12½ dia. ..	110,000	1½	76,000–152,000	1–2

The figures in Table I are based on 2 in. W.C. manifold pressure, and on 1,000 B.th.u./cu. ft. natural gas with 10% excess air.

Suggested Definitions of Terms used in Spectrographic Analysis

THE lack of uniformity in the choice of symbols and terms associated with spectrographic analysis is causing some concern and members of the Spectrographic Discussion Group, of Glasgow, decided to examine, critically, the symbols and terms in common usage and to formulate definitions applicable to analysis by emission spectrography in an attempt to introduce some measure of standardisation. Previous lists of definitions published in the *Analyst* in 1937 and 1942, intended to cover related fields of optical and allied sciences, are considered not sufficiently detailed to cover practical emission spectrography.

The result of detailed discussions extending, at intervals, over a period of some two years, is published in a booklet recently issued, which may be accepted as the considered opinion of the Group. It should be noted, however, that the symbols and definitions listed are tentative and should be regarded as a basis for discussion among other groups interested in spectrographic analysis. The Glasgow Group believes that results from discussions of these suggested definitions of terms could be included in a more comprehensive scheme covering subjects such as absorption spectrography, radiography, and others of an allied nature.

The Group will welcome any criticisms or suggestions regarding these tentative definitions, and interested readers are advised that copies can be obtained, free of charge, on application to The Spectrographic Discussion Group (Mr. S. D. Steele), Research Department, Messrs. Babcock & Wilcox, Ltd., Renfrew, Scotland.

Production of Magnesium Sand Castings

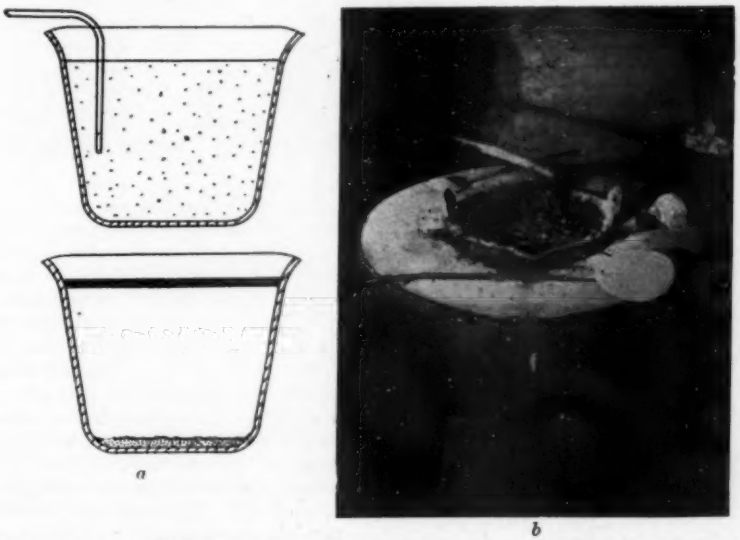
Melting Technique and Grain Refinement

By G. B. Partridge, A.I.M.

Production Metallurgist, Elektron Foundry, Birmingham Aluminium Castings (1903) Co. Ltd.

In this section attention is directed to the melting of magnesium alloys and to the technique involved. Included in the discussion are the types of fluxes used; the melting units, with special reference to melting pots; preparation of the metal for casting, including superheating, grain refinement and the gas effect.

ALL metals other than the "noble metals" such as gold, silver and platinum begin to combine with the oxygen of the air more or less readily when sufficiently heated, and magnesium is so chemically reactive that not only does it combine easily with oxygen to form magnesium oxide but also reacts with the nitrogen to form magnesium nitride. Small amounts of these compounds occur usually in the form of skins of a greyish character, the nitride imparting brown or golden effects and the whole possessing a metallic lustre; the formation of greater amounts, however, produces a crumbling residue of grey and white powder. The usual Elektron alloys begin to liquate at about 440° C. and are completely molten at about 620° C. when, unless precautions are taken, extensive oxidation will occur and will proceed at an increasing rate. Unlike the aluminium alloys, the oxide film on the magnesium alloys offers no protection, because, it is not continuous and its presence as such accelerates further oxide formation; as this reaction is exothermic, the heat evolved increases the speed of the reaction still further. It becomes clear, therefore, that the mere addition of fluxing agents to clean the melt, as is practised with many of the other metals, is inadequate when dealing with the magnesium alloys and it is essential to maintain complete protection by means of fluxes throughout the whole melting cycle. Mention should be made of the fact that successful attempts have been made to melt magnesium alloys without flux in a special atmosphere, but such methods do not result in clean melts and processes using fluxes are far superior.



a *b*

Fig. 1.—(a) Diagrammatic representation of method of cleaning Elektron magnesium melts. (b) Pot of magnesium alloy being "washed."

Types of Flux

The early fluxes of German origin consisted mainly of magnesium chloride in the form of raw carnallite and, although thickening substances were added, the fluxes were frequently much too fluid, with the result that complete separation from the molten metal was difficult and flux inclusions occurred which set up corrosion centres in the castings. Modern melting procedure is to use two distinct types of flux, one, a thinly fluid type which has a low melting point and has great wetting power, and the other a much more viscous type which is used when the rising temperature of the melt makes the use of the fluid type inadequate. It used to be stated that the base of all good magnesium melting fluxes was magnesium chloride, but this is not necessarily so and research in recent years has reduced the need of this expensive material considerably. The present day fluxes are marketed under the trade name "Melrasel" and are protected by patent specifications; the composition of the fluid type designated "Z" is mainly a mixture of the chlorides of magnesium, calcium sodium and potassium and of the viscous type designated "E" a mixture of the above chlorides plus some magnesium oxide and calcium fluoride to impart the necessary thickening effect.

The function of the "Z" type of flux is to give the metal protection during the melting down stages, when burning is liable to occur through awkward pieces of scrap becoming "scaffolded" across the pot. Its low melting point enables it easily and freely to coat the metal surfaces with a thin film of excellent wetting power, which, besides preventing further air attack, rapidly absorbs oxides, nitrides and extraneous matter. When the melting unit is full of molten metal and the temperature begins to rise the second flux "E" is brought into use, and its functions are twofold: (*a*) To "refine" the melt of all impurities and disseminated particles of the fluid flux; and (*b*) to form a stable protective cover on the surface of the liquid metal during the superheating and cooling cycle and the subsequent pouring. The first of these effects is interesting and is called the inspissating action, because the special

Fig. 2.—Pouring D.T.D. test bars.

composition of the flux enables it to thicken up the particles of "Z" flux it encounters along with impurities, causing the whole to sink to the bottom of the pot in a coherent mass.

Melting Units

Oil, gas, or electricity can be used as the fuel in magnesium melting plants. A German source states that the successful use of electrical energy followed the adoption of an induction furnace which contained a removable iron pot of the type usually met with in handling molten magnesium; high efficiency and complete control were claimed for this method. Although no large scale electric melting plant seems to have been developed either here or abroad, there does not appear to be any technical reasons against its use, probably, however, the cost factor weighs heavily against it and at present oil or gas fired melting units are favoured.

Provided that due care and attention to detail is paid, there is really no limit to the size of unit that can be employed for magnesium melting, but there is distinct differentiation between the sizes employed due to their separate functions—i.e., they are divided into small and large units.

The small units usually consist of pressed or welded steel pots of $\frac{5}{8}$ in. sectional thickness with capacities ranging from about 80–500 lb. of magnesium alloy and are used for the direct pouring of castings, whereas the large units consist of steel pots of approximately 2 tons capacity for bulk melting. The majority of pots are made from mild steel which is perfectly satisfactory, the only precaution necessary is to keep the nickel content at minimum, as the tolerance limit for nickel in the magnesium alloys is so low that the slightest pick-up will endanger this with consequent decrease of corrosion resistance.

The construction of the furnaces holding the melting pot is an important point and the following factors should be borne in mind as necessary to obtain maximum economical efficiency: (*a*) The combustion of the mixture (when using either oil or gas) should be controlled, for example, by means of enclosed burners, to produce a slightly reducing atmosphere, which will retard the formation of scale on the pot; (*b*) the combustion chamber size and shape should be calculated to assist complete combustion; (*c*) flues should be controlled to produce the necessary furnace atmosphere pressure to yield high efficiency; (*d*) consideration should also be given to multi-burnering and fluing, recuperation or the self heating of incoming air, and the use of low-heat capacity brickwork.

The scaling of the pots and consequent concentration of scale in the bottom of the furnace during magnesium melting is a serious matter apart from the economic factor and should be closely watched, because in the event of a run out violent reaction will occur between the molten metal and the iron scale, possibly resulting in an explosion. Besides the attempts to maintain a reducing atmosphere, fuel with low sulphur contents should be preferred and a method of metallising the pots with aluminium seems to have yielded very encouraging results and may be worth trying.[1] A similar method was tried by the author some years ago, but due to faulty bonding of the aluminium and steel did not prove a success.

Safety precautions taken daily consist of hammering the base of the upturned pot when hot with a 2 lb. hammer, a suitable opportunity being just after a cast; if a dent can be made the pot is not used again. A further check consists of testing the wall thickness by means of calipers for dangerous thin spots, but a watchful furnaceman will notice defective areas, when the pot is red hot, revealed as black patches caused by the fluxing salts filtering through.

The use of large units in this country is confined to the ingot producers, but in America much work has been done with a view to using such types in foundries[2] and there does not seem any reason why their use should not be entirely satisfactory. Oil or gas-fired bulk melters should be economical on fuel and a pair working in conjunction could feed several small units with liquid metal, which, after final fluxing and grain refining, could handle very large scale castings production. The scheme incorporating a centrifugal pump for metal transfer mentioned by Eastwood, Davies and DeHaven[2] is typical of American ingenuity and it is only a short step to the direct filling of moulds with such a device; these ideas are worthy of deep consideration in the search for lower production costs.

Melting Process and Preparation of Metal for Castings

No matter how good a machine the use of alternately "full throttle and stop," must impose the maximum stress on the machine and likewise erratic use of virgin ingot/scrap ratio in magnesium melting introduces unnecessary variables and should be avoided by good teamwork between foundry production and technical management. To obtain maximum economic working the above melting mixture ratio must closely approximate to the metal poured/fettled castings ratio, and if this procedure is followed increased smooth working will result.

Using a new steel pot in the furnace it is usual to lightly sprinkle the interior with Melrasel fluid flux "Z" and put in the necessary amount of virgin ingot, which, taking the above views into consideration, would probably be about 40% of the charge. The sprinkling of flux prevents burning of the metal on incipient melting. It is advisable to charge as much scrap as possible immediately on top of this virgin material so that the whole is able to progressively melt without large additions of flux becoming necessary, an occasional dusting being quite sufficient; it also ensures that the solid added metal has a thorough preheat before sinking into the liquid mass. As melting proceeds more scrap is added and any local burning promptly quenched by the application of the "Z" flux. It is important that additions of metal should cease when the level of the liquid bath is from 3–4 in. below the rim of the pot, so that subsequent fluxing operations may be carried out vigorously; furnacemen frequently fill their pots

1 Keller, A.V., "Magnesium Melting Pots," *Metal Industry*, April 19th, 1946.

2 Eastwood, L. W., Davies, J. A., and DeHaven, J. C., "Recent developments in Magnesium," *Light Metal Age*, Feb., 1946.

too full in an endeavour to squeeze an extra casting from the one melt. Clean scrap of the riser type can be used direct from the fettling shop, but any contaminated with sand or dirt must be grit blasted before use; recovered ingoted scrap is usually quite suitable without further treatment.

When the charge is completely molten, cleansing or washing of the melt can proceed and the classical method of fluxing as outlined by the ingot producers is as follows: A layer of Melrasel "E" is applied to the surface of the molten metal, which will melt while the temperature is being raised to 730°–760° C., and, when this has been achieved, this flux cover is vigorously stirred into the metal with a rotary motion until it sinks to the bottom of the pot carrying with it all oxides, impurities and inspissated globules of the fluid "Z" flux (see Fig. 1). After completion of the stirring process which takes about two minutes the metal should possess a bright silvery surface and is prevented from burning by the immediate application of a layer of Melrasel "E." The stirrer should consist of about ½ in. steel rod bent at right angles, but bent hollow tubing with the end hammered up is frequently used in spite of the possible dangers accompanying such a practice as, due to the larger cross sections the furnacemen are able to get an easier swirl of the metal with the larger melts.

3 Emley, E. F., "The use of fluxes in the melting, refining and casting of magnesium-base alloys," *Magnesium Review and Abstracts*, Vol. IV, No. 1, Jan., 1944.

b c

Fig. 4.—Larger view of test-bar heads (b) and (c).

Furnaces are usually placed on the floor of the melting shop, but sometimes are preferred sunken in the floor so that the surface of the melt is well below the furnacemen and so facilitates the stirring process.

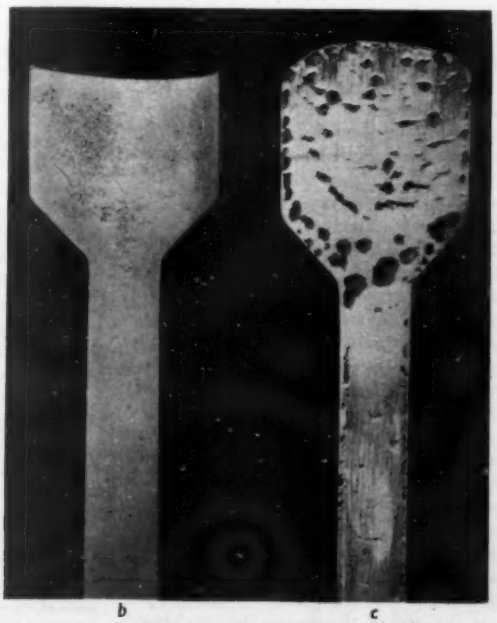
The Melrasel "E" is referred to as the refining flux and the stirring process is known as refining, but the term must be used in the sense that it means purifying and not a refinement of grain size. American workers have remarked that simple stirring of a magnesium alloy melt produces grain refinement but there is little evidence to support this view.

Modifications of the above fluxing procedure exist with regard to the respective amounts of flux used. A layer of Melrasel "Z" is sometimes applied after initial melting and is stirred in before the application of the Melrasel "E," this is very useful in the case of dirty melts and no harm will result as it is followed by a wash of Melrasel "E."

A single flux for melting, refining and subsequent covering has been compounded and is used by some founders, but should excessive oxidation

a b c

Fig. 3.—(a) Test bar taken from normal melt; (b) test bar from melt moderately gassed; (c) test bar from melt severely gassed.



b c

Fig. 5.—Section through bars showing: (b) Medium porosity; (c) severe cavitation.

occur during melting this type of flux is not so easily able to absorb the oxides produced.

While the washing process is going on heat continues to be applied to the pot with consequent rise of temperature, after covering the surface of the metal with flux heating is still continued and is known by the term "superheating," but almost all magnesium castings are poured at a temperature below 800° C. and therefore the extra heat is not applied to increase fluidity. The purpose of the superheating process is to refine the grain size and will be referred to later; it is important to note that gradual superheating followed by comparatively rapid cooling yields the best results. The melt is usually superheated to 900° C. after which the flame is turned off and after persisting at this temperature for a little while heat losses cause the melt to cool down, alternatively the pot can be removed from the furnace and cooled down more rapidly.

Castings are usually poured at temperatures ranging from 750°–800° C. depending upon sectional thickness, and the metal is poured as soon as the desired temperature is reached, the following procedure being adopted. The pouring spout and adjacent edges of the pot are cleaned of encrusted flux and the flux cover (which is now somewhat caked) pushed away from the pot lip with a skimmer; pouring commences at once, the stream of molten metal being protected from oxidation by the immediate dusting of flowers of sulphur.

Should the castings be subject to A.I.D. inspection, test bars are poured at a temperature of about 780° C. in the usual D.T.D. type mould by hand ladle taken from the pot prior to making the castings (see Fig. 2). Assuming that good fluxing technique has been carried out it is possible almost to empty the pot of clean metal in making the castings without fear of flux contamination; the small amount of metal which does remain is usually poured off into another melting charge or is ingoted out. The flux residue remains as a blackish stodgy mass and the pot is tipped up in a bin and the residue thrown violently out, the pot picked up by crane, replaced in the next vacant furnace and the melting procedure repeated; no preliminary dusting of flux is necessary, however, when re-charging a used pot. It is good practice to "water clean" pots at the end of the day: this is carried out quite simply by filling each pot with water and allowing it to stand for about 24 hours during which time all encrusted dirty residues are leached away; sufficient pots to cover two working days must be in use to enable this to be carried out.

The inherent difficulties which accompany the manufacture of magnesium castings inevitably increase the overhead charges by the cost of the materials necessary to effect their solution, it is important, therefore, for technicians to see that the melting and fluxing process is accurately carried out or metal loss will be considerable. The "net melting efficiency" should be over 97% when metal output is expressed as a percentage of the metal input; metal output being defined as poured castings plus recovered metal poured off into the next charge so that the operation from start to finish should not involve metal losses above 3%.

Grain Refinement

The most popular magnesium alloys of the aluminium containing type possess a remarkably fine and silky structure, the grain size in a test bar, under normal production conditions, being of the order of 0·1 mm. or less. For many years the method of producing this beautiful structure has been by the superheating process described in the preceding section, but the reasons why such a procedure brought about grain refinement have eluded all research efforts. Fox and Lardner[4] have done a large amount of work in an endeavour to discover and explain the phenomena and are of the opinion that a nucleating constituent is responsible but they have not been able to identify it. The proven facts of years of industrial experience, however, are that: (*a*) Only the aluminium containing alloys react to the superheating process; (*b*) the superheating effect is dependent upon the time/temperature cycle—i.e., the larger the melt the longer must be the time allowed to raise the melt to the superheating temperature, which is usually 900° C.; (*c*) the grain refinement effect may be lost if the melt is held at a temperature of 680°–700° C. for a while. A peculiar fact noted by the author, especially when using well worked foundry scrap, was that material which apparently resisted grain refinement on superheating also would not coarsen, or was difficult to coarsen, when holding at a low temperature. The highest obtainable mechanical properties of the magnesium alloys are obtained by the refinement of grain and close grained metal is an essential feature and fundamental requisite of good quality castings.

The disadvantages of the superheating process are mainly economic not metallurgical and include: (*a*) Extra cost of fuel required for the superheating operation; (*b*) reduction of the life of the steel pot through the high temperatures involved, and (*c*) time taken up by the operation increases overhead costs of the foundry.

Great interest was aroused when American workers discovered that elementary carbon and some of its compounds were capable of producing grain refinement at comparatively low temperatures. The process is sometimes known as inoculation and so rapid has been the investigation and subsequent adoption of the process that to-day a very large number of magnesium castings are produced from metal which has been refined by this means, which consists of introducing carbon in the form of a gas or volatile compound into the melt at a temperature of about 740° C. and cleaning or washing the melt with flux in the usual way afterwards. Mechanical properties of optimum values are obtained and grain sizes comparable with or even better than those produced by superheating are at once encountered and it is impossible to tell the difference between either method by microstructure or by fracture test, further, the metal has the same tendency to coarsen at temperatures around 700° C. whether it has been superheated or treated by the carbon process. The effect is again attributed to clouds of nuclei and some workers think that they may consist of compounds of carbon and aluminium which may precipitate early on in the solidification process.[2] It would be very satisfying to be able to prove conclusively that the above explanation is correct, but there is another factor which does not seem to have been considered and that is the effect of iron.

During the superheating process relatively large amounts of iron are dissolved in the molten metal and precipitated upon cooling, and during the war German workers have been doing research work on grain refinement largely based upon the effect of iron and its compounds.

The treatment is known as the "Elfinal process" and consists of plunging 0·5–1% of the metal charge of anhydrous ferric chloride into the molten magnesium at about 760° C.

4 Fox, F. A. and Lardner, E., "An exploration of the problem of superheating in magnesium-base alloys," *Jour. Inst. Metals*, **71**, Serial No. 98:.

whereupon superheating above 830° C. is rendered unnecessary. Claims made for the process include the production of a finer grain and better mechanical properties than that obtained hitherto, reduction of fuel consumption, a considerable saving of melting time and an increased crucible life.

It is quite certain that the author has produced fully fine grained Elektron alloy test bars and castings from extremely coarse grained ingot by simple melting and fluxing in a new but slightly rusty steel pot to a temperature not exceeding 780° C. The original material was so coarse and the resultant rapid grain refinement so spectacular that it was concluded that the loosely adherent rusty iron deposit must have produced the refining effect.[5]

Some of the claims put forward by American workers for the new processes are unfortunately inclined to be extravagant and misleading, in as much as, in hailing the new discovery, they seek to discredit the older superheating and fluxing procedure. It must never be forgotten that superheating did the job and did it well, and the major number of magnesium castings produced in this country during the recent war were made by these older methods, which, for freedom of inclusions and fineness of grain, were unequalled throughout the world.

The Gas Effect

The usual statement made regarding the susceptibility of magnesium alloys to gas absorption is that there is no gas problem analogous to that which occurs with the aluminium alloys—i.e., the pinholing effect revealed upon machining. Unfortunately the old adage, "what the eye doesn't see . ." has taken on a new aspect with regard to the presence of gas in magnesium alloys and the complete absence of pinholing has led many to believe that no gas problem existed at all. This is quite wrong and it has been established that unless certain and very definite precautions are taken when melting magnesium alloys in the foundry, serious defects occur in the resultant castings.

The only gas, however, which needs to be guarded against in this respect is hydrogen and it seems very certain that it must be nascent or atomic to do real damage—i.e., it is the gas released during chemical reaction of hydrogen containing substances with magnesium which dissolves easily in the melt.

5 Internal Reports. Birmid Industries.

Both British and American workers[6, 7] have done considerable research and useful work on the gassing of melts with hydrogen, but the only real thing which remains in doubt is the effect of small traces of hydrogen, because, in spite of the list of cautions outlined in one report,[7] there are only two ways of introducing the gas in easily recognisable amounts and they are: (*a*) Scrap coated with corrosion products; (*b*) castings which have been doped with substances such as linseed oil. Whether or not flux will gas a melt easily is somewhat obscure for many thousands of routine foundry melts have given almost unwaveringly first-class test bar figures for long periods, but the effect of different types of fluxes on a melt, already severely gassed, is quite noticable, insomuch that one type tends to help the release of gas from the melt and the other retain it; the good test bar results referred to above must have been the result of first-class melting practice.

Hydrogen absorption in magnesium alloys reveals itself upon solidification in two ways—namely, the formation of worm like, fairly large holes and a considerable increase in the amount of micro-porosity, these effects are sometimes accompanied by rapid spurting of the riser head as solidification approaches, sometimes by the appearance of exudations on the riser face (Fig. 3), but sometimes there is no external phenomena at all.

The presence of gas is easily discerned internally, however, by the prevalence of micro-porosity and the golden scintillating effect sometimes found on the fracture, but the effect on the mechanical properties is always drastic and castings suspected of being made from gassed metal should on no account be allowed to leave the works; it is important to remember that the diffusion of the gas can be so rapid through the metal and concentrations be in heavy sections, such as risers, that, although covering test bars may betray the defect, thin sections of the castings may be quite free, on the other hand rapid chilling may prevent egress of the gas.

The presence of the gas in a melt can either be prevented or cured, prevention consists of the maintenance of dry storage conditions for flux, complete abstinence from the use of ingot surfaced with corrosion products (grit blasting is a good help here) or metal which has been "doped," and the use of a good melting process as outlined earlier. Should some unfortunate happening have caused the melt to contain gas its ejection is best obtained by bubbling chlorine through it, but, although this is undoubtedly an excellent method, manufacturers in this country usually prefer to use other means owing to the cost of plant and hazards involved in the use of chlorine. An alternative method consists of vigorous and frequent stirring, whilst holding the melt at a low temperature, followed by pre-solidification before use, tests should be taken to ascertain the success or otherwise of this procedure and if doubtful must be repeated. Methods involving the use of a degasser, which is incorporated in the carbon compound used during the modern grain refining process, are advocated but as yet they have not been developed to a degree when they yield completely satisfactory results; research in this direction should prove of great value to the industry.

6 Baker, W. A., "Micro-porosity in magnesium alloy castings," *Jour. Inst. Metals*, 71, 1945, Pt 4.

7 DeHaven, J., Davies, J. A., and Eastwood, L. W., "Reduction of Micro-porosity in Magnesium Alloy Castings," *Amer. Foundryman*, June, 1945.

Antimony

ANTIMONY was known to the ancients. The black sulphide was used as a cosmetic, according to records dating back some 5,000 years. The metal was used in jewellery and ornamentation. Furthermore, the Egyptians knew how to "plate" antimony on copper and bronze.

At present antimony figures very prominently in international trade. Like tungsten, tin and copper, it is a "key" metal, an essential metal difficult to replace by any other. Antimony possesses a number of distinct physical and chemical properties that make substitution well nigh impossible.

In nature antimony usually occurs as sulphide, stibnite, Sb_2S_3, disseminated in siliceous rocks and generally associated with quartz. Of secondary commercial importance are the double sulphides such as pyrargyrite $3Ag_2S.Sb_2S_3$, tetrahedrite $4Cu_2S.Sb_2S_3$, and others. Although antimony is very widely distributed in the earth's crust, the three chief producing countries are China, Mexico and Bolivia. Radical changes have been taking place in the world's antimony trade during the last two or three years. Thus, for example, whereas formerly 80–90% of the antimony consumed in the United States came from China, to-day Mexico and partly Bolivia furnish 90%.

From *Bull. Electrochem. Soc.*, July, 1946.

Military Applications of Electroplating in the Recent World War*

By WILLIAM BLUM

Electroplating was more widely used during the recent war than during the 1914–18 *war, due primarily to technical advances in deposition, increased intricacy and precision of military weapons, and shortage of strategic metals. Some of the many applications are briefly reviewed by the author, the main features being presented here in a somewhat condensed form.*

FAR more extensive applications of electroplating on military supplies were made in the recent war than during the 1914–18 war. This fact was doubtless due to the joint result of such factors as: (1) Advances in electroplating, especially in its technical control and specification; (2) increased intricacy and precision of military weapons; and (3) shortage of strategic metals as a result of the unprecedented scale of military operations. As a consequence of the large military applications, the total volume of plating conducted up to V-J day was probably greater than in a corresponding peace time, though the types and applications were different.

The applications of electroplating to military supplies were far too many to enumerate, much less to discuss fully in any brief report. They included large quantities of supplies for "military housekeeping," which did not differ essentially from normal civilian products, except insofar as substitutions were made for strategic metals. Only minor reference will be made to these applications of plating.

The uses of plating on specialised equipment for ordnance, aviation and communications involved in many cases the selection of metal coatings to meet unusual or severe conditions. Even though these particular conditions may not exist in domestic or industrial operations, the experience gained in the war may point the way to significant industrial developments. Details of many of the military uses have not been released, so that only brief references may be made to them at this time.

At best, any such summary will be incomplete, but it is hoped to make it sufficiently comprehensive to indicate the scope of these uses of electroplating. No effort will be made to give specific credit for each development, but pertinent specifications and publications will be referred to. The important applications will be classified in accordance with the principal metals deposited.

Deposits of Specific Metals

1. *Chromium.*—The extensive pre-war use of bright chromium—e.g., on automobiles, was almost completely abandoned with the curtailment of civilian products, and very little bright chromium was employed on military supplies. However, the use of "hard chromium" on dies, gauges, moulds, and many forming and cutting tools increased and contributed directly to the war effort by prolonging the useful life of manufacturing equipment under very drastic service conditions. The use of chromium plating to salvage worn parts also increased. Most of these applications were extensions or modifications of pre-war practice.

Chromium plating of large naval guns had been practised for many years, but no detailed studies of the plating and performance of different types of guns had been conducted. During the war extensive researches on the cause and prevention of gun erosion were conducted by the National Defence Research Committee. In this connection studies on chromium-plated gun bores were made by the National Bureau of Standards in co-operation with the Geophysical Laboratory, the Franklin Institute, and the War and Navy Departments. Similar work was conducted by Battelle Institute and also by the Armament Research Department in England. The detailed results of these studies have not been released. They led to the adoption in calibre-50 barrels of chromium plating over nitrided steel or in conjunction with stellite liners.

One significant result of these investigations is a realisation of the wide variation in properties of chromium deposits. The ordinary chromium used for both hard and bright coatings, deposited—e.g., at 45°–55° C. and 10–30 amp./dm.², has a hardness of about 900 Brinell. It is brittle and contains cracks that increase in size and number when heated, as a result of its contracting by as much as 1%. This type of chromium may contain over 1% of Cr_2O_3. In contrast, chromium deposited at about 85° C. and at 40–120 amp./dm.² is relatively soft—i.e., about 450 Brinell, and does not contract or crack appreciably when heated. It contains only about 0·2% of Cr_2O_3. The regular deposits were designated as "high-contraction" and the softer as "low-contraction" chromium.

The largest war-time development of chromium deposition was the use of "porous chromium" or "oil-absorbent chromium," on cylinders of aircraft and Diesel engines and piston rings. This process depends upon the fact that ordinary hard chromium deposits usually contain fine cracks. If the surface is etched—e.g., anodically, these cracks are enlarged, to produce a surface which retains lubricating oil and thereby reduces wear.

Two types of porosity may be distinguished—viz: Type I or "channel" porosity, in which the depressions are connected to form a fine net work of channels; and Type II or "pin-point" porosity, in which the pores are distinct and not connected by channels. The specifications for porous chromium for a particular purpose usually define the final thickness, type of porosity, and the "per cent. porosity"—i.e., the proportion of the surface represented by the pores or channels.

Porous chromium was successfully applied for the

* Presented at the 90th General Meeting of the Electrochemical Soc., October, 1946.

salvage of aircraft cylinders, which in many cases had a much longer life than the new, unplated cylinders. It was extensively applied to Diesel engine cylinders and to piston rings. It will no doubt have many post-war uses.

2. *Nickel.*— During the early part of the war the greatly increased demand for nickel in steels used for tanks, guns and armour plates prohibited the use of nickel plating not only on civilian goods but also on most military supplies. For example, it was only by great effort that small quantities of nickel were released for plating of steel surgical instruments. Serious but not very successful efforts were made to salvage the nickel present in the then unused nickel plating baths in large plants.

3. *Copper.*—While copper was not so relatively scarce as nickel, its use in plating was restricted. Some of its applications rested on the fact that thinner coatings of copper could be applied by plating than otherwise. Much copper-clad steel with fairly thick copper coatings was used for such purposes as bullet jackets. On calibre 0·45 ammunition, however, the bullet jackets consisted of steel electroplated with about 0·0005 in. (13 microns) of copper.

Another extensive use of copper coatings, usually produced by chemical immersion, was on steel to lubricate it during drawing operations – e.g., in making steel cartridge cases. Copper was plated on certain areas of aluminium radio and radar equipment, to facilitate soldering. Certain applications of copper electroforming proved valuable, such as the production of Pitot tubes and aeroplane models. Copper plating was extensively used to protect steel surfaces during case-hardening.

4. *Zinc and Cadmium.*— These two metals may well be considered together because they both give sacrificial protection to exposed steel, and to some extent are interchangeable, In fact, the scarcity of cadmium during the war led to the substitution of zinc for cadmium wherever feasible. Extensive exposure tests have shown that, under practically all atmospheric conditions, a given thickness of zinc yields at least as much protection against the corrosion of steel as the same thickness of cadmium. Cadmium, however, preserves a better appearance and is less likely than zinc to form bulky white corrosion products. The latter objection to zinc was overcome for many purposes by the application of a supplemental chromate film. Owing to the scarcity and greater cost of the cadmium, its coatings were usually thinner than those of zinc.

In order to prevent brittleness caused by plating, both zinc-plated and cadmium-plated steel springs were heated to expel hydrogen. No conclusive data are available regarding the relative embrittlement produced by zinc and cadmium plating. Many of the cadmium-plated parts were dipped in chromic acid solutions to improve their appearance or the adhesion of paint; while zinc-plated parts often received chromate or phosphate treatments.

One important application of zinc plating was on steel cartridge cases. Extensive corrosion and firing tests showed that good performance could be secured with steel cases that were either zinc-plated and given a chromate finish, or were coated with a baked phenolic varnish.

Early in the war large quantities of fuse parts were cadmium plated, but subsequently zinc plating was largely substituted. Cadmium plating was preferred to zinc on radio chassis and other parts, though on condensers, as previously reported, cadmium coatings sometimes developed fine "whiskers" that caused short circuits. Many applications of zinc plating arose from the substitution of plain-carbon steel for stainless steel, brass, aluminium and zinc die castings. Zinc-plated steel mess kits were used for a short time, but were objectionable because the zinc is readily attacked by acid foods, to form emetic though not seriously toxic compounds. The coinage of zinc-plated steel pennies for one year saved over 5,000,000 lb. (2,300 metric tons) of copper.

5. *Lead.*—The relatively greater availability of lead than of zinc resulted in considerable substitution of lead coatings on steel. "Terne plate" (steel coated with a hot-dipped layer of lead containing 10%–25% tin) had been extensively used for years for roofing, which was generally painted. Scarcity of tin necessitated a reduction in the tin content of terne plate to 2·5%. It was then found that for many purposes lead-plated steel sheet was equally satisfactory, though results recently reported indicate that some tin in the electrodeposits increases their protective value. All of these uses of lead-coated steel depend upon the fact, not fully appreciated in earlier years, that even though lead coatings permit initial corrosion of steel exposed through any pores, they tend to be "self-healing"—i.e., to seal the pores and to prevent continued corrosion of the steel.

6. *Tin.*— Cutting off the supplies of tin from the Orient necessitated drastic conservation of tin for both military and civilian purposes. Before the war, most of the hot-dipped tin plate used in the canning industry carried about 2 lb. of tin per base box, equivalent to about 0·00012 in. (3 microns) of tin. It was not found practicable to reduce this thickness much below 1·25 lb. per base box (1·9 microns) by the hot-dipping process.

Studies and experience before the war showed that by plating it was possible to produce tin coatings down to 0·5 lb. per base box (0·00003 in.) and thereby to extend the supply of tin that was available. Several large strip-plating plants were installed, in some of which acid baths were used, and in others alkaline stannate solutions. In plating flat sheets or strips, the difference in throwing power of these baths is not significant. One important difference in the two types of bath is that the acid baths require tanks with rubber or other acid-proof coatings, while the alkaline baths can be used in unlined steel tanks.

Even relatively thick hot-dipped tin coatings are notably porous. The thin electrolytic tin coatings were more porous than the ordinary hot-dipped tin though usually less so than an equal thickness of hot-dipped tin. To improve the appearance and solderability of the electrolytic tin and to reduce its porosity somewhat, the electrolytic coatings were melted, either by a flame, hot oil, resistance heating, or induction heating.

For some purposes, especially "dry packs," thin electrolytic tin was satisfactory. For other uses it was inferior, even when lacquered, and for some purposes it was quite unsuitable. It is probable that electrolytic tin, especially with intermediate weights— e.g., 0·75 to 1 lb. per base box, will find a permanent place in industry but will not entirely displace hot-dipped tin.

7. *Silver.*—The most extensive use of silver plating was for lining bearings for aircraft engines. The principal new problems to be overcome were to increase the speed and uniformity of deposition and to secure the most perfect adhesion. Success in achieving these goals on a on a very large scale is a tribute to "electroplating

engineering." Ingenious methods of testing the adhesion of the silver coatings were developed, including a high-speed centrifugal test.

These silver bearings were usually coated with a lead-indium alloy, which is resistant to corrosion by the lubricants. A coating of lead was first applied to the finished silver surface, followed by a thin layer of indium, after which the combination was heated to a low temperature to alloy the lead and indium. This application of indium illustrates the fact that rare or unusual metals may find specific uses.

One new, important application of silver plating was on parts of radar equipment. This use depends on the fact that most of the conduction of very high-frequency current is a "skin effect" and that hence the maximum conductivity of the surface layer is desirable. A coating of about 0·0002 in. (5 microns) of silver was generally employed. Silver is the best conducting of the metals, but is subject to tarnish, especially by sulphides. Silver sulphide is a conductor, but not nearly equal to silver. Application of a thin film of palladium over the silver surface to prevent tarnish was proposed but not extensively used. Gold plating was also applied over silver, or as a substitute for silver.

8. *Platinum Group Metals.*—Rhodium plating was applied in several plants to large electroformed searchlight reflectors. Rhodium has a reflectivity of only about 75% as compared with 95% for clean silver. However, silver readily tarnishes and is softer and more easily scratched than rhodium. Some success was obtained with lacquered silver coatings, which yielded higher initial reflectivity than rhodium.

9. *Miscellaneous Applications.*—The use of iron deposition as a substitute for at least part of the copper and nickel normally used in electrotypes proved to be feasible, but was not widely adopted. Instead, measures were taken to salvage most of the copper used in electrotyping. This was done largely by electrorefining methods adapted to these particular materials.

Most of the war-time plating was applied to steel, partly because of shortages of non-ferrous metals. Efforts were made to substitute plated plastics for the plated brass in buttons and insignia. These appeared to be satisfactory, but were not extensively adopted. Some of the well-known discharge buttons were made of plated plastic.

Some developments were made in alloy deposition. "White brass" deposits, and also white deposits consisting of copper, zinc and tin were announced. While these were applied successfully to some articles, few large military uses were made of them, partly because of the scarcity of tin.

There was considerable increase in the use of coloured coatings on metals, some produced by immersion and some by electrolysis. Among the former were several methods of producing black oxide films on steel in hot nitrate and nitrite baths. These coatings furnished little protection against rust unless they were supplemented by suitable films of oil or wax.

The anodizing of aluminium and electrolytic methods of protecting magnesium alloys represents processes allied to electrodeposition that were very extensively applied, especially on aeroplane parts.

Copper Alloy Resistance Materials

THE desirable characteristics of resistance materials in general with special emphasis on the need for high resistivity and low temperature co-efficient were briefly considered by Dr. H. G. Taylor in his introduction to the above subject which he discussed at a recent meeting of the Society of Engineers. Of lesser significance are the features that the corrosion resistance should be high, material should be ductile, its electrical characteristics should be uniform and permanent over a long period of time, and it should be readily possible to weld and solder the material. For certain purposes also, it is desirable that material should exhibit a low thermoelectric E.M.F. against copper.

The most commonly used alloy is that containing 40/45% nickel and 60/55% copper. This alloy is generally known as Ferry or Eureka, though it is also sold under a number of other trade names. The resistivity is about 50 microhms/cm³ and the temperature co-efficient is practically zero. Copper-nickel, manganese alloys of the Manganin type are used for instrument work and for standard resistances. Similar properties are exhibited by copper-nickel-aluminium alloys which have been introduced in recent years.

The introduction of pure manganese in America has made it possible to use straight copper-manganese alloys which are workable up to 98% manganese. These have resistivities up to nearly 200 microhms/cm³ and if special heat-treatment is applied values as high as 500/1,600 microhms/cm³ can be obtained.

Attention was drawn to the care required to produce wire and strip to comply with B.S. specifications which deal with resistance alloys. The convertion of strip and wire into resistances and rheostats was illustrated by a number of slides illustrative of typical British plant.

Selling Prices of Copper, Lead and Zinc

THE Minister of Supply has made the Control of Non-Ferrous Metals (No. 26) (Copper, Lead and Zinc) Order, 1946, which came into force on January 1st, 1947. This Order revokes the Control of Non-Ferrous Metals (No. 25) (Copper, Lead and Zinc) Order and increases the maximum prices of copper, lead, zinc and zinc products as follows:—

The price of high-conductivity electro copper is increased from £98 to £117 per ton; of good soft pig lead (Empire and domestic) from £55 to £70 per ton; and of zinc (g.o.b. domestic and prime western) from £55 to £70 per ton. Prices for other forms of these metals are correspondingly adjusted. The price of zinc sheets is increased from £66 2s. 6d. to £81 2s. 6d. per ton ex works, and for red seal zinc oxide from £56 to £68 15s. per ton delivered with a similar increase for the other forms of zinc oxide.

The above increases reflect the recent sharp upward movements in metal prices which have taken place outside the United Kingdom and which in turn affect the purchase prices paid by the Ministry.

Copies of the Order may be obtained from H.M. Stationery Office, Kingsway, London, W.C.2, or through any bookseller, price 1d. (S.R. and O., 1946, 2205).

Jacketed Type Steel Drier Rolls

By William H. Funk

Development Engineer, Luken's Steel Company

As a result of a failure of a cast-iron drier roll and the urgent need for a replacement, a welded steel single shell drier roll was installed. So successful did this development prove to be that the use of welded steel drier rolls for a wide range of purposes has become a general practice. The author discussed this development at the recent annual meeting of the American Society of Mechanical Engineers, the main features of which are given in the article.

THE replacement in a bank of cast-iron drier rolls by a welded steel single shell roll, because it could be obtained quickly, provoked considerable thought and discussion as a result of the increased operating efficiency and longer bearing life, through improved journal design, which the steel drier roll gave. These advantages have continued over more than 12 years of almost continuous service rendered by the drier roll, which is operating in a mill making paper board. Since then, steel drier rolls have been accepted by many different industries such as paper making, printing, textile, film processing, plastics, rubber and chemical.

There were few who thought that this steel drier roll would differ much in performance from the conventional type then in general use. However, it was considered that, by means of fabricated steel design, an improvement on several features inherent in conventional single shell drier roll design, could be effected. A large diameter single shell roll requires very thick head sections which contribute substantially to the weight of the roll. If the steam could be confined to an annular space between two shells, this heavy design could be eliminated. The higher strength of steel plate would allow the use of lighter gauges for the shells, so that two shells plus internal stiffeners would weigh little, if any, more than a single cast iron shell. This weight reduction would be very beneficial in service. Fig. 1 shows jacketed drier rolls of this design before machining. They are 6 ft. diameter by 5 ft. face. The journals were machined for roller bearings and a drive gear, and the face was machined to a polished finish. Fig. 2 shows a drawing of a section of this roll in which the absence of heavy sections will be noted.

In this double shell design the flat-head plates, which close off the ends of the steam chamber and support the shells by spokes from the journals, also provide the means of passing steam into the annular shell space. Half-pipe sections, welded to the spokes, and holes drilled in the inner shell and journals, form a steam passage through one journal, across the face of the roll and out the other journal. Some of the earliest jacketed-type steel drier rolls designed and built in this manner were used by a publishing company to dry printed ink.

The next consideration in furthering the design of the jacketed-type drier roll was better condensate removal. Jacketed-type steel drier rolls already built were operating very satisfactorily and more were being fabricated. However, it was acknowledged that a more positive method of removing condensate should be incorporated in future designs. As a result a drier roll was built with

Fig. 1.—Jacketed-type drier rolls before machining Each is 6 ft. dia. with a 5 ft. face.

two provisions for condensate removal incorporated in the design. Fig. 3 shows this drier roll which is 8 ft. diameter by 6 ft. 10 in. face. Every section on this drier roll is now serving a double function, since each piece is a strength member and is also part of a steam passage. The steam inlets have become pipe spokes, and the end plates have become rings acting as closure plates only. The condensate provision used at slow speeds is a scoop arrangement and was designed to pick up the water lying at the low point of the drier and remove it. At higher speeds when the condensate rotates with the roll this scoop would not remove the condensate. A pipe, therefore, is inserted through the inner shell so that the open end of the pipe is very close to the inner surface of the outer shell. This pipe draws off the condensate leaving a water film, the depth of which is equal to the clearance between the pipe and the shell. Valves in these condensate lines make it possible to use the drier roll at any speed and still evacuate the condensate. The passage of steam in this drier roll is through one journal, into the pipe spokes at both ends of the roll, and into the jacket space, from the centre of which, by one system or the other, the steam and condensate are removed through the opposite journal. The pipe spoke design is an improvement over the one used in the earlier drier rolls because in the current design there are no unheated sections to restrict roll expansion. Stiffeners on the inner shell have been eliminated. These drier rolls may be closed at the ends to keep heat losses from the inner shell at a minimum.

The operation of this drier roll definitely indicated that the jacketed-type design was more efficient than a single shell design. The roll was first operated at the

speed and steam pressure previously used with the cast roll it replaced. Flashing and burning of the tissue paper being made, resulted. To produce the paper satisfactorily the steam pressure was reduced to less than 5 lb./sq. in., and the speed of the machine was increased. Later the pressure was raised slightly and the speed increased still further. This jacketed-type steel drier roll, currently produces more paper than was possible with the cast-iron roll, although it uses exhaust steam instead of live steam direct from a boiler. Tissue paper has been creped from this roll ever since it was installed and the doctoring action has not been detrimental in any way. This doctoring is a scraping action on the face of the roll, while it is in operation, for the purpose of creping, flaking, cleaning or polishing.

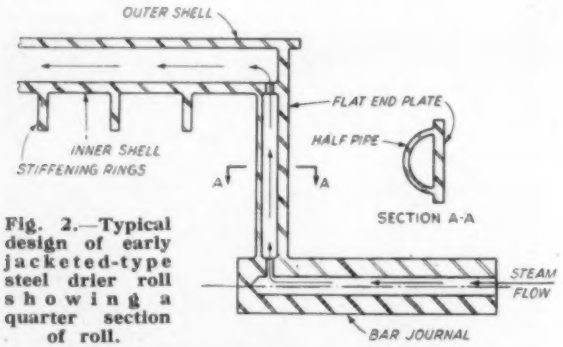


Fig. 2.—Typical design of early jacketed-type steel drier roll showing a quarter section of roll.

The field of use for these jacketed-type steel rolls was also extended, while the design was being developed. Jacketed-type rolls 10 ft. diameter were fabricated for use in the processing of light plastic films. The nature of the product requires that these rolls, designed to use warm water as a heating medium operate with a very uniform surface temperature. In this case, small pipes, through which the warm water is distributed, connected the jacket with the diffusing manifold inside the inner shell. The pipe spokes on each end of the roll became the return lines only.

For high-temperature requirements of around 370° C. jacketed-type rolls are supplied to chemical manufacturers. These rolls have a variation of the jacketed-design which may best be described as a labyrinth for the circulation of any special heating medium. Fig. 4 shows such a drier roll with a cutaway section revealing the labyrinth design. Rolls of this type are particularly applicable for installations requiring very high pressures, very high or low temperatures, or where a heavy load is applied externally. The total thickness of the shell plate may be about 2½ in., with the steam passages still very close to the outer roll surface. In some cases the drier is designed to use steam at 150 lb./sq. in. in the labyrinth-type construction of the shell plate.

The acceptance of these jacketed-type drier rolls for a variety of uses offers proof of their value in most industries where the principle of drum-drying is used or is applicable. The advantages to be gained by the use of this type of roll for drying, cooling or any other processing done on drum-type rolls can be grouped in several categories. First, welded steel fabrication makes possible a wide range of roll design from which a roll can be readily adapted to a specific use. Second, the design selected contains mechanical advantages that are not found in any other type rolls. Third, the jacketed-type

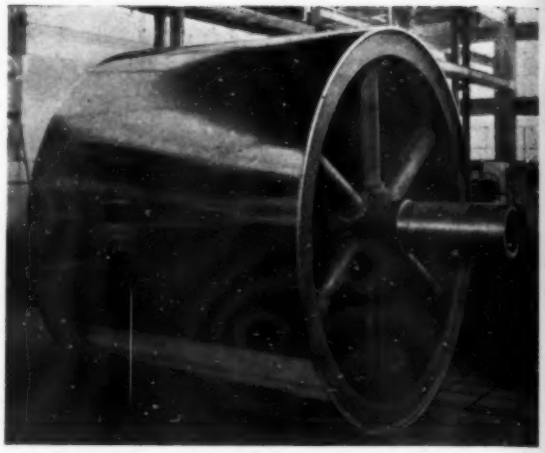


Fig. 3.—A jacketed drier roll of more modern design, 8 ft. dia. with a 6 ft. 10 in. face and weighing nearly 8 tons. Each section of this roll serves a double function, as a strength member and as part of a steam passage.

steel roll also has features which will raise its operational efficiency above that of the conventional-type rolls. Fourth, these advantages generally reflect savings in initial costs, operating expenses and operating time.

The design of a jacketed-type steel roll is limited only by the imagination of the designer, who must, however, acknowledge certain physical limitations which cannot be overlooked. Among these are transportation problems. The fabricating facilities available must be considered. Can a cylinder 10 ft. 0 in. in diameter with a 16 ft. 0 in. face be formed from a plate of 2 in. thick steel? Are assembling and welding facilities adequate for the design contemplated? Are furnaces available to stress relieve a roll of the size desired? Stress relieving is considered a necessity if the roll is to hold its true shape in operation. The manner of stress relieving has also been found to affect the dimensional stability of the machined drier roll. Are the machining facilities available for a roll of the size contemplated and can the type of finish desired be obtained? These are typical limitations mentioned because they are the only kind of physical limits imposed on the designer. The designer must also consider rigidity and strength under operating loads and pressures.

These limitations are in no way alarming for the possibilities in welded steel designs are virtually untapped. Rolls can be made for higher pressures than were ever practical before. They can be made so that they will give constant and uniform temperatures over the face. A jacketed-type steel roll also can be designed with solid stainless steel shell or with a clad steel shell to resist corrosion or prevent contamination of the product. The jacketed-type steel roll can be designed for use when chromium, nickel or other plating is desired on the face.

The mechanical advantages incorporated in the design vary to a degree with the size of the roll and the design selected. A jacketed-type roll 3 ft. 6 in. O.D. and under, will not be lighter than a typical single shell roll, but larger diameter rolls do show an appreciable weight saving which is reflected immediately in the design of the supporting frames and in the drive unit for the roll or rolls. The bearings for the roll can be smaller because

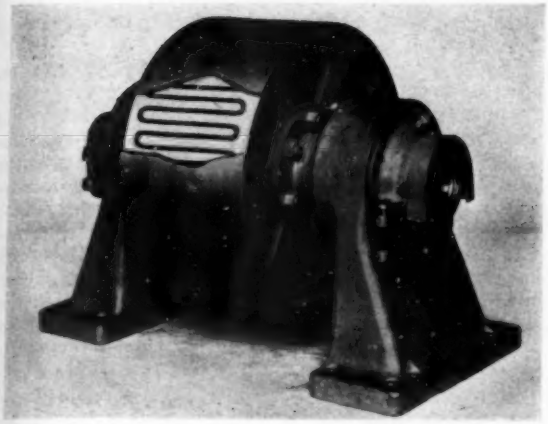


Fig. 4.—Steam platen adapted for use as a drier roll with section cut out to show internal labyrinth. In operation, cold water or a refrigerant will circulate through the labyrinth of the drum. Drier rolls of this type from 2 ft. dia. upwards are used.

of this weight saving and also because the relative strength of steel versus cast iron permits designing smaller journal diameters. There is added mechanical safety in the use of welded rolls in case of failures under pressure. If, for any reason, too much pressure is applied to the roll, the steel plate will distort to a noticeable extent before fracture occurs.

The welded roll, designed correctly for its intended use, has operational advantages over a conventional-type roll. The jacketed design, which is adaptable to most uses, guides the steam in a restricted area across the inner surface of the race of the roll. The net cross-sectional area inside the roll which contains steam is, therefore, much less than that of a single shell roll. If it were assumed that a jacketed-type drier roll in operation has the same surface speed, operating pressure, rate of drying of paper and rate of condensation in the roll as does a single shell roll, one thing becomes apparent: the steam velocity in the jacketed roll must be greater by the same ratio as the net cross-sectional area is smaller. In considering what this greater steam velocity does in the jacketed-type roll it is found that, first, it reduces the film on the inner surface of the shell plate. This film offers considerable resistance to heat transfer through the shell. Second, it minimises the possibility of dead steam in the roll. Steam is guided into this jacket through a series of inlets spaced around the roll in a manner designed to keep all the steam in the roll in controlled motion. Third, the feature not only of channeling all the steam but also moving it at a higher velocity, is better insurance that air in the entering steam will be flushed out immediately with the exhaust steam and condensate. Dalton's Law of Partial Pressures states that the total pressure exerted by a mixture of gases is equal to the sum of the pressure which each gas would exert if it alone would occupy the whole volume. This law can be interpreted to mean that any air in the steam chamber of the drier roll will cause the actual steam pressure to be lower than that indicated by a gauge in the steam line. As a result, the temperature in the drier roll will not correspond with the steam temperature at that pressure. Just a small percentage of air in the roll reduces the drying rate of the machine. Fourth, the greater velocity of the steam and the guiding feature of the narrow steam passage maintain a more uniform surface temperature across the face of the roll. Also, the rate of heat transfer improves as the steam velocity increases.

By examining the assumption, with these features in mind, it is apparent that the rate of drying must increase because the conditions tending to retard heat transfer have been improved. Increased drying ability must be offset by increasing the operating speed if the residual moisture content of the sheet being dried is to be held constant.

Unfortunately, the nature of this increased operating speed, which is a measure of the productive efficiency of the drying machine, cannot be calculated to any degree of accuracy. There are too many indeterminate variables in a drier roll section of a machine in addition to the roll itself that have a direct bearing on the drying rate.

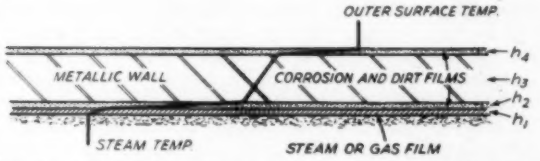


Fig. 5.—Section through a metallic wall showing the effect of condensate corrosion and dirt films on the transfer of heat through the walls.

The basic formula for heat transfer is as follows:—

$$Q = U \times A \times \Delta T$$

Where Q = Heat transferred in BTU/hr.

U = Over-all coefficient of conductance in BTU/hr./sq. ft./° F.

A = Area in sq. ft.

And ΔT = Temperature difference in ° F. between the steam and the sheets to be dried.

The value for U can be derived from the following formula:—

$$U = \frac{1}{\frac{1}{h_1} + \frac{1}{h_2} + \frac{1}{h_3} + \frac{1}{h_4}}$$

Where h_1 = Conductance of condensing steam

h_2 = Conductance of film on inside of shell (dirt, scale, etc.)

h_3 = Conductance of metal shell

h_4 = Conductance of film on outside of shell.

Consideration of the various components of the over-all conductance, shown in Fig. 5, is of interest. The jacketed-type steel roll is not thought to affect appreciably the values of h_3 and h_4. It is known, however, that better heat transfer is obtainable from jacketed driers without altering the drying area A or the temperature differential ΔT. It is assumed then, that h_1 and h_2, the conductance of the condensing steam and the inner film, are the factors which cause this better heat transfer. How to evaluate this assumption is not definitely known. Much more development is required before the best heat transfer rates will be obtained for the jacketed design. The only reliable methods known to measure the increased efficiency of a drying machine, which may be due to the use of a jacketed-type steel drier roll, are a practical test or by laboratory research. It should be pointed out, that regardless of the type and weight of

the sheet being dried, a function of the drier roll is always to promote the evaporation of moisture from the sheet. Most of the heat absorbed during evaporation is supplied by the latent heat released when steam in the roll is condensed. Basically, then, a better heat exchanger will be a better drier, provided the additional heat is released through the shell and is not lost through radiation from the ends of the roll. To reiterate, increased drying ability must be offset by increasing the operating speed if the residual moisture content of the sheet is to be held constant.

A practical test performed in the following manner confirms the theoretical assumptions which have been mentioned. Ten jacketed-type steel drier rolls were installed in a paper machine in a felt mill to replace 10 cast driers in a bank of 54 single shell cast iron rolls. This felt mill produces the felt base for roofing materials and for floor coverings such as linoleum. The operating steam pressure for the cast iron rolls was 50 lb./sq. in., while the pressure of the jacketed rolls was increased to 150 lb./sq. in. No other changes in the machine, or in its operation, were made. The production rate was increased approximately 8–10% over the average rate before the replacement. Where corresponding increases in pressure and temperature are possible this increased efficiency presents an interesting comparison. Keeping in mind that this installation has only 10 out of 54 rolls changed it can be assumed that at 150 lb./sq. in. pressure the jacketed drier rolls show an increase in efficiency of from 40–50%. The efficiency increase, due to the increased pressure based on data collected from several sources, is estimated to be about 30–33%. The remaining increase in efficiency of about 15% must be attributed to the jacketed steel design of the drier rolls.

In order to determine the relative efficiency of the jacketed-type steel drier roll at the original operating pressure of 50 lb./sq. in., the pressure on the steel drier rolls was reduced to 50 lb./sq. in. and observations were made with the machine running under conditions similar to those existing before the steel drier rolls were installed. Results indicated that the residual moisture content of the sheet was 28% less when the steel drier rolls were used, and that the average operating speed was increased 4·6%. Again, noting that only 10 of the 54 rolls were replaced with steel drier rolls, it can be seen that each jacketed-type steel drier roll demonstrated an increase in efficiency of nearly 25%.

A conservative appraisal of this practical test indicates that 18% is a safe figure for increased efficiency of small diameter drier rolls. This figure is much more conservative for large diameter drier rolls.

The hazards in fabricating a welded steel roll are not so great as in casting a roll. The larger the roll the more apparent this becomes. If, for instance, a shell plate for a steel roll is damaged in processing it can be repaired or replaced for a fraction of the cost of casting a new roll.

Operational costs also may be reduced by virtue of reduction in weight and design. Lighter equipment requires less horsepower for driving. The jacketed-type steel drier roll requires no shut downs for tightening bolts to stop steam leakage. The jacketed design reduces the time required to-bring the roll to operating temperature. The usual starting delays are cut to a minimum whether the roll is operated with steam or with water, because there is no large volume of cold water in the bottom of the roll to be removed or to be brought to temperature. For an equal number of driers, the operational costs per ton of finished product are reduced when the operating efficiency is increased.

Difficulties were encountered in developing the jacketed-type steel drier roll to its present status. Fortunately, however, they were generally fabricating problems and were confined to the weld shop. The experience gained through the solution of these problems has contributed greatly to the development of these drier rolls to their present standards. Data are available on the fabrication of nearly 200 steel drier rolls now operating in many different industries. All these rolls have satisfactory performance records and most of them have been contributing factors in increasing production on the drying machines in which they are operating.

There are certainly some problems which are yet to be overcome by the designers of jacketed-type steel rolls. Steel plate used to form the outer shell of the drier roll has been developed to provide the soundness required for any type of machine finish, including the highly polished surface needed as a base for plating. At present, however, a weldable steel is not available to give a surface hardness comparable to cast iron. This may or may not be detrimental when doctoring is necessary on the drier roll. Successful installations where doctoring is performed have been discussed. Additional research by both steel fabricators and manufacturers of doctor blades to improve this condition is still to be performed. Present designs available for jacketed-type rolls undoubtedly will be improved as more actual operating data are collected. The increased efficiencies known to-day are a challenge rather than a goal achieved.

An Aluminium Bridge to Span the Wear

HEAD WRIGHTSON & Co., the engineers of Thornaby-on-Tees, announce that the River Wear Commissioners of Sunderland have placed with them a contract for the supply and erection of a twin leaf bascule bridge to be manufactured in aluminium alloy. This will be the first aluminium moving bridge in the world and follows a year's development work undertaken by their subsidiary company, Head Wrightson Light Alloy Structures Ltd. When open the bridge will give a clear waterway of 90 feet. It is pointed out that a considerable saving of steel, and therefore of fuel, has been effected by the employment of aluminium. Although a small bridge has been constructed in aluminium in America, this will be the first moving bridge to be made in aluminium in the world. It is worthy of note that over 100 years ago Sunderland had a cast iron bridge erected over the Wear.

The engineer to the River Wear Commissioners is Mr. W. H. F. Tripp.

Aluminium Wire & Cable Co. Ltd.

THE Aluminium Wire & Cable Co., Ltd., which was formed recently by The British Aluminium Company Ltd., Hawker Siddeley Aircraft Co., Ltd., and Tube Investments, Ltd., has arranged to purchase premises at Port Tennant, Swansea, from the Ministry of Supply and will enter into occupation as from May 1st, 1947. Modifications to buildings and the installation of plant will be carried out as soon as possible, and it is anticipated that some production will start towards the end of the year.

The Company has offices, temporarily, at Salisbury House, Circus Place, London Wall, London, E.C. 2.

Production of Cemented Tungsten Carbide

By Stuart H. Brierley

The manufacture of tungsten-carbide alloys is a highly specialised industry, about which the average engineer is unfamiliar, and the brief outline of the processes involved, given in this article, is intended to supply information on the subject. Two processes are discussed, the double-sinter and the single-sinter methods and brief reference is made to the advantages of each.

DUE to the stimulus of the recently ended war the full importance and usefulness of tungsten-carbide alloys, in all branches of engineering, has been realised, and in this country there is a well-equipped and flourishing industry with big markets to satisfy both at home and abroad. However, in spite of its present widespread use in industry, the average engineer has little or no knowledge of the methods of manufacturing, due to the extreme specialisation of the work. In the following paragraphs, therefore, it is proposed to give a non-technical résumé of two of the manufacturing processes in the hope that it will interest and provide information for those unfamiliar with the subject.

The two processes are the "double-sinter" method and the "single-sinter, hot-pressing" method. Sinter is a term applied to rocks precipitated in a crystalline form from mineral waters, but in its application to cemented tungsten carbide it refers to the operation in which tungsten-carbide powder with cobalt powder as a binder are subjected to heat of a temperature which causes the tungsten-carbide particles to shrink and the cobalt to flow, thus cementing the tungsten carbide particles together.

Preparation of Tungsten Carbide Alloy

The preparation of the tungsten-carbide alloy in powder form is carried out in a similar manner for each process and it would be as well to deal briefly with this aspect of production, because the quality of the final product is dependent, to a considerable degree, on the care exercised in this initial work.

The tungsten is obtained in powder form from the reduction of tungstic oxide which is prepared from tungsten ore. This reduction is carried out with charcoal in a closed electric furnace at a temperature of approximately 1,400° C. in a pure, dry, hydrogen atmosphere. The finished tungsten powder must have a purity of at least 99·5% and a fine, regular grain size. Carbon in the form of acetylene soot is then added and the mixture ball-milled, using methyl-alcohol or distilled water as a wetting agent, for 6–12 hours. The resulting paste is then spread on metal trays and placed in an electric oven where the wetting agent is slowly evaporated. This usually takes about 12 hours.

After drying, the tungsten and carbon mixture is crushed to a powder and passed through an electric furnace in graphite containers with a reducing atmosphere of hydrogen. This carburising operation is carried out at a temperature of 1,450°–1,500° C. and takes from 3–4 hours. The resulting compound of tungsten carbide is grey in colour and soft and chalky in texture. It is again ball-milled, but without the addition of a wetting agent, for approximately 6–12 hours and a fine grey powder results. A sample of this is taken to determine the amount of free and combined carbon. This is very important as unless the tungsten is properly carburised the qualities of the finished alloy will be affected.

Tungsten carbide alone is too brittle to be of any use, so cobalt metal powder (produced by reduction of cobalt oxide in an atmosphere of hydrogen at a temperature of approximately 600° C.) is added. This mixture is ball-milled with a wetting agent for two to four days, depending on the grain size required. After milling the mixture is dried, crushed and sieved, and after a sample has been analysed to check the percentage of combined carbon, free carbon, cobalt and also the grain size, it is ready for use.

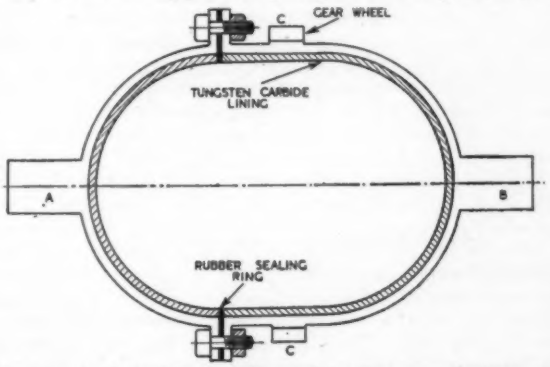


Fig. 1.—A typical ball-mill used in the manufacture of tungsten carbide.

Typical Ball Mill

Reference has been made to ball-milling the mixture to produce the requisite fineness and a typical mill for this purpose is shown in Fig. 1. It consists of a steel container made in two sections and preferably lined with tungsten carbide. The capacity of these mills averages about 5 kilograms. The mills are loaded with the required alloy, the wetting agent added and then tungsten carbide balls, about 1 in. in diameter put in. The two sections are secured and located on bearings and supported by the lugs A and B, at the same time the gear-wheel C, which can be an integral part of the steel casing, engages with a smaller gear which transmits the drive from an electric motor. The speed of rotation of the mill varies from 24–120 r.p.m. and the time of milling varies between 24–72 hours according to the type of alloy being processed.

Value of Cobalt Additions

The addition of cobalt to the tungsten carbide and the subsequent ball-milling, which hammers a coating

of cobalt round the particles of tungsten carbide, facilitates the bonding or cementing of the carbide particles during sintering. Thus the finished product has a much greater resistance to shock whilst the hardness of the tungsten-carbide itself is unaffected either before or after sintering.

The percentage of cobalt used is varied in accordance with the requirements for the finished product. For general purpose work 8–10% cobalt is used. If a harder alloy is required, less cobalt is added, if a softer one, the amount of cobalt is increased. For the machining of very hard steels, carried out at high speeds, titanium, vanadium or boron is added as well.

Double Sinter Process

At this point the manufacturing processes diverge and a brief description will first be given of the double sinter method. In the process the tungsten-carbide powder is pressed in hardened steel dies of the required shape with a lubricant such as paraffin wax or camphor to expedite and assist the operation. The pressures applied vary and may be as much as 300 tons/sq. in. according to the alloy used. After compressing, the solid carbide is partially sintered at a temperature of approximately 1,000°–1,100° C. to enable shaping and forming to be carried out. Shaping is done on grinding machines to within close limits of the final dimensions, using special abrasive wheels. After this the final sintering takes place. This operation is difficult and requires exact control of temperature, length of heating and length of cooling. The carbide is placed in graphite containers and covered with carbon powder. It is then passed through an electric furnace in an atmosphere of pure dry hydrogen at a temperature of 1,400°–1,500° C. From the heating zone the containers enter a metal, water-cooled jacket until quite cold. The time taken for this final sintering is between 2/4 hours, according to the exact nature of the alloy required. Final polishing is then carried out on special machines using diamond wheels, handlaps and paste. The carbide is then ready for mounting on a shank or in a die case, for whichever use it has been made.

Single Sinter Process

In the single sinter process the moulds are made of graphite as this is claimed to be the most suitable material to withstand the high temperature involved. The mould is filled with the alloy and placed in an electric furnace where it is subjected to heat and pressure simultaneously. Pressure used is about 1,000 lb./sq. in., and the final temperature is in the region of 1,500° C. When cool the graphite is sandblasted away from the finished metal which is then ground by hand on a green-grit carborundum wheel to remove any fins formed during sintering. Grinding to size and polishing is then carried out, and the carbide mounted for use.

Comparison of the Processes

The merits and demerits of the two processes must be carefully considered in determining which to adopt.

For wire-drawing dies of fine bore and for complex shapes, the double sinter method is believed to be the best, due to the fact that the carbide can be machined to within very fine limits of the required size after the first sintering and therefore only requires polishing after the second and final sintering. Also the steel moulds can be used over and over again whereas the graphite moulds can only be used once.

In the case of the single-sinter, hot-pressing method, fine bores and complex shapes are difficult to machine in the graphite material used for the moulds, and the graphite is also liable to break during the sintering operation when machined to fine proportions. Any shape or bore required must generally be formed during the sintering as afterwards the only way of altering the shape is by grinding with diamond wheels, which is expensive. However, on bores over 0·100 in. diameter and on straightforward shapes this method is quicker and cheaper, also the finished alloy is denser due to the sintering and compression taking place in one operation. A further advantage of the single sinter method is that the existing plant, without any modifications or additions, can be used to manufacture metal bonded diamond grinding and cutting wheels. A suitable metal bond, such as iron and copper or copper and cobalt, in powder form, is mixed and milled with diamond powder of the required grain size, this is then put into moulds and subjected to simultaneous heat and pressure exactly as the tungsten-carbide alloys. As the manufacture of tungsten-carbide and bonded diamond wheels are definitely allied industries this last mentioned advantage weighs heavily in favour of this process, especially in the case of the small manufacturer.

In the manufacturing of tungsten carbide on a comparatively large scale, however, it seems desirable that both processes should be used, in order to make full use of the separate advantages of each.

"Bristol" Pegasus-Engined Flying Boats Perform Well

PERFORMANCES by the "Bristol" Pegasus-engined Short "C" Class flying boats which operated the U.K.-Durban service for B.O.A.C. until its cancellation last December, are clearly revealed in some information received from a B.A.C. Engine Department representative in South Africa. The fleet, based on Durban, comprised 13 flying boats each powered by four "Bristol" Pegasus XXII engines. None of the aircraft has flown less than 1,000,000 miles and five have each covered more than 2,000,000. These five machines, Castor, Canopus, Caledonia, Cameronia and Carpentaria, have between them flown 10,335,238 miles, the total for the whole fleet being 23,490,013 miles. This figure is equivalent to each aircraft having flown around the world at the equator rather more than 72 times. The average ground speed was 128 knots or 147 m.p.h. Flying hours for the 13 boats total 171,406, which corresponds to each machine having remained continuously airborne for 549 days.

Throughout these intensive operations, the petrol consumption for each team of four Pegasus engines averaged 130 gallons per hour. This speaks well for the construction and design of the power units, many of which have a total of over 5,000 engine hours to their credit and some as many as 8,000.

The popularity of the Durban flying boat service was such that the announcement last December of its cancellation evoked a storm of protest. The South African public has now won its way to keeping its favourite service and, although the "C" class boats are going into honourable retirement, the traditions of the service will be maintained by a new product of "Bristol" and Short teamwork—the fast and comfortable Solent, powered by "Bristol" Hercules engines.

Modern Methods of Gas Analysis

Part II.—The Orsat Gas Analysis Apparatus

By W. D. Vint

The Orsat gas analysis apparatus is discussed and some hints on its correct maintenance are given. Particulars of the reagents used are also given and the operation of the apparatus described, including a graph indicating the number of c.c.s. of gas which can safely be exploded when its calorific value is roughly known.

FOR general purposes when a quick fairly reliable analysis is required, there is little to surpass the ordinary Orsat apparatus. A wide range of illuminating and heating gases can be analysed within the half hour to a percentage accuracy of 0·1. A great number of different forms and improvements on the original apparatus are on the market, but the principles are the same in every case. The apparatus consists essentially of the following items :—

1. A gas burette graduated in tenths of a c.c. Usual capacity is 100 c.c.s., but 50 and 200 c.c.s. burettes are sometimes embodied in special forms of the apparatus.

2. Vessels to hold the absorbents of the particular constituents of the gas. Here again there is a choice of several types of absorbtion pipettes and care should be taken to ensure that the most efficient types are chosen for the apparatus.

3. Explosion pipette in which the combustible gases are exploded with air or oxygen. Sometimes the graduated tube itself is utilised for the explosion of these gases and direct readings of contraction, etc., can be taken.

4. A reservoir containing the sealing liquid, be it mercury, brine, or acidulated water, is connected to the bottom of the graduated tube.

5. Other fittings or modifications which are sometimes present on the apparatus should a special analysis be required.

A typical form of the apparatus is shown in Fig. 1. The confining or sealing liquid in this case is water, to which is added about 1% of sulphuric acid and a few drops of fairly strong methyl orange. Before an analysis is carried out, this liquid must be gas saturated; the most convenient method is by allowing a sample of gas (any illuminating gas containing CO_2 will suffice) to stand in the apparatus overnight. By such means any tendency for the liquid to absorb small quantities of gases (notably CO_2) is satisfied. This precaution also applies if brine or any other aqueous solution is used for the confining liquid.

The apparatus shown in Fig. 1 possesses a water jacket surrounding the graduated tube. Any sudden changes of temperature (even the heat from an operator's body can cause a slight temperature rise) must therefore be absorbed by the surrounding liquid before its effect is felt on the gas sample. It should be borne in mind that quite small temperature changes can cause considerable changes in the volume of the gas.

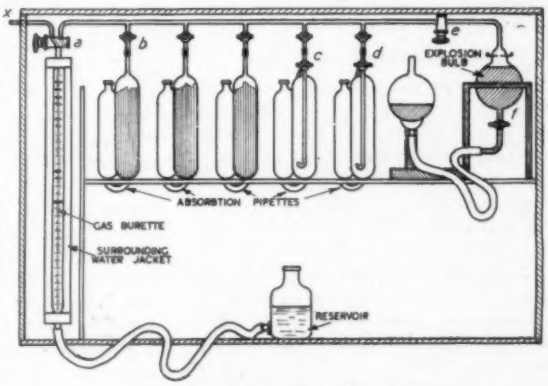


Fig. 1.—Orsat apparatus.

Alterations in barometric pressure also cause volume changes in a gas, but as the pressure is very unlikely to alter considerably during the short space of time in which an analysis is carried out, this discrepancy is very seldom taken into account.

The gas pipettes as shown in Fig. 1 are of two types :—

1. The Brighton. One disadvantage of this type of gas pipette is the additional two-bore cock which is needed. Caustic and bromine solutions tend to dissolve the grease film of the tap with resultant sticking and clogging of the bore.

2. Glass tube. This type of gas pipette contains a bunch of glass tubes or beads. No double-bore tap is necessary and solutions need not come into contact with taps at all. In the opinion of the author, the ideal arrangement is for pipettes containing caustic and bromine solutions to be of the glass tube pattern. No trouble with sticking or clogging taps will then be encountered.

The explosion bulb as shown in the apparatus is separate. Here again are advantages and disadvantages. An explosion in a spherical bulb is much more likely to result in complete combustion of a gas than an explosion in a long narrow tube. This is particularly important when gases of rather low calorific value are being exploded; flame propagation throughout a tube becomes more difficult with increase in length of tube and with decrease in calorific value. On the other hand the separate explosion bulb as shown necessitates an extra two taps and the transfer of the gas from the graduated tube and back again. This all increases the slight possibility of inaccuracy due to loss. Summing up, therefore, gases of fairly high calorific value should preferably be analysed on Orsats which incorporate the graduated tube for explosion purposes, whilst gases of low calorific value should be analysed on Orsats where the explosion tube is separate.

At the top of the explosion tube two small contacts of platinum wire are let into the glass to form a gap of $\frac{1}{16}$ in. The source of high voltage current necessary to jump this gap

can very conveniently be obtained from an induction coil powered either by a six-volt battery or a step down mains transformer.

Accurate analyses of gases of fairly low calorific value can be obtained by actually burning the gas mixed with oxygen or air. Instead of the two contacts, a small platinum spiral of about 42 S.W.G. is enclosed in the tube and heated to redness by passing a 6-volt current from the battery or mains transformer across it. A rheostat of about 10 ohms should be included in the circuit as a protection against overheating. The gas of low calorific value can be passed over the glowing spiral several times, even the smallest traces of combustible gases are burned.

Before the method by which the apparatus is operated is described, a few hints on correct maintenance will not be out of place. These subsequent remarks apply generally to most types of gas analysis apparatus.

Maintenance of Orsat

1. All taps must be kept adequately greased. Once a week at least each tap should be removed, cleansed under running water, wiped dry, and greased with a thin consistent film of grease (not enough to accumulate and clog up the bore). The tap socket also, should be cleaned and wiped dry.

2. If the apparatus is in constant use the reagent solutions must be renewed at frequent intervals. With normal usage, reagents should last about a month when it pays in increased speed of operation and accuracy to renew them. The cuprous chloride and pyrogallol solutions can be further assisted in retaining their gas absorbing properties by pouring a ¼ in. layer of a light mineral oil or paraffin over the exposed surface in the back limb. Bromine solution cannot be treated in this way owing to its reaction with oils or hydrocarbons.

3. Rubber connections must be kept in a good state of repair. Rubber perishes very easily when in contact with certain chemicals and an apparently innocent looking piece of rubber tubing can cause endless trouble should it be pierced with microscopic holes. Rubber connections must be as tight as possible, the thick walled variety of rubber tubing is best and wiring of joints is unnecessary providing tubing really fits.

Reagents

The reagents contained by the gas pipettes are as follows :—

(*a*) Caustic potash solution for carbon dioxide absorbtion. Prepared by dissolving 1 lb. of pure KOH (caustic potash purified by alcohol should not be used) in 400 c.c.s. of water. Allow solution to cool before charging pipette.

(*b*) Bromine water for absorbtion of unsaturated hydrocarbons. A few drops excess bromine should be added to the reagent.

(*c*) Alkaline pyrogallol solution for absorbtion of oxygen. Prepared by dissolving 10 grams of pyrogallic acid in 100 c.c.s. of caustic potash of 1·5 specific gravity. The solution should be allowed to cool and stand about 24 hours before use ; if it is required for use immediately the solution should be boiled for a few minutes and allowed to cool. Alkaline pyrogallol will last indefinitely in a well-stoppered bottle, but when in constant use and with no means of regeneration its life is fairly short. When the solution is found to be losing its absorbing power, renew as soon as possible.

(*d*) Acidical cuprous chloride solution for absorbtion of carbon monoxide. This reagent is prepared by dissolving 80 grams of cuprous chloride in 600 c.c.s. conc. HCl and adding a further 200 c.c.s. of water. The stock solution should be well stoppered and should contain a few bars of metallic copper as a preventative against oxidation. Instead of acidical cuprous chloride the copper salt can be made alkaline with ammonia. Some chemists prefer ammoniacal cuprous chloride which is made up as follows :—

Stock solution.—Dissolve 250 grams. ammonium chloride in 500 c.c.s. of water, add 200 grams cuprous chloride and water again to 750 c.c.s. Leave solution for 24 hours before using and shake before use. Solution for the pipette is made by adding 43 c.c.s. conc. ammonia to 123 c.c.s. of stock. Mix well and pour into pipette.

Operation of Orsat

Shall we assume that a sample of coke-oven gas is to be analysed? Raise the reservoir and open tap "a" to atmosphere. When the tube is full of liquid close tap "a." Connect sampling tube to point "x" not forgetting to stand the tube in a large beaker of acidulated water or brine. Open bottom tap of sampling tube beneath brine and open top tap to apparatus. Stand the reservoir on the bench and open sampling tube tap and tap "a." When about 100 c.c.s. of the gas has entered the burette close tube tap and tap "a." Bring the reservoir to a position such that the level of liquid is on a horizontal plane with the level of liquid in the gas burette. The volume reading of the gas at atmospheric pressure can now be taken and booked (assume 100·0 c.c.s.). Raise reservoir, open tap "a" to the long capillary tube and pass the gas into pipette containing caustic potash. Halt the process before liquid reaches the top of the gas burette and lower reservoir before gas is pulled back into the burette. By simply repeating the whole process the gas should be passed into the KOH pipette at least once more. Close taps "a" and "b" and measure the new reading on the burette by bringing the gas to atmospheric pressure (Assume 97·8). Check that no more CO_2 is present in the gas by passing once more into the KOH and remeasuring. There should be no decrease in volume.

Similarly, the oxygen percentage can next be determined by passing gas into the alkaline pyrogallol pipette and remeasuring gas under atmospheric pressure. (Assume reading to be 97·6). The gas should next be passed into the bromine solution until a constant reading is obtained. (Assume reading to be 95·5). Carbon monoxide is next eliminated by passing into the cuprous chloride pipettes. Greater difficulty is usually experienced in dissolving all the CO out so care should be taken to ensure that a final constant reading is obtained. (Assume this to be 89·6).

In Fig. 1 there are two cuprous chloride pipettes. The gas should be bubbled about two or three times through the first one and the second pipette can then be used for the removal of the final traces of the CO. This arrangement works most efficiently and frequent changing of cuprous chloride pipettes is eliminated. When the gas is drawn back into the burette do not forget to reverse taps "c" or "d" as the case may be.

So far, the constituents of the gas which have been determined are CO_2, O_2, C_nH_m (unsaturated hydrocarbons) and CO. The remaining constituents are CH_4, H_2 and N_2, of which the two combustible gases CH_4 and H_2 can be determined by explosion. The number of c.c.s. of the residual gas which is taken for explosion purposes is rather important if adequate measures against too violent an explosion are to be taken. The number of c.c.s. which can be safely exploded is governed by the calorific value and the graph compiled is illustrative of this fact. Knowing roughly the calorific value of the gas the number of c.c.s. which can be

safely exploded can be obtained from the graph (Fig. 2). Assuming that in this particular case the calorific value is 460 B.Th.U's, from the graph 12·0 c.c.s. can be safely taken. Similarly, any other type of gas can be safely exploded, providing a rough knowledge of its composition is known. Oxygen or air which must next be

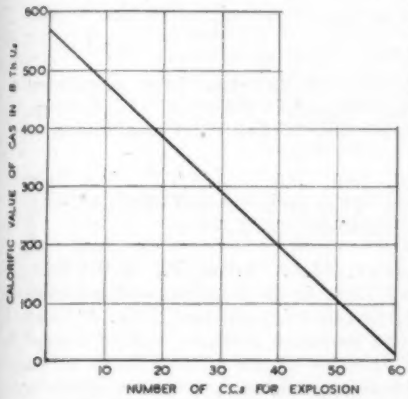


Fig. 2.—Graph showing approximate relationship between calorific value of gas and safe number of c.c.s. which should be taken for explosion.

added to the gas before explosion must be added in excess. From the elemental equations:

$$2H_2 + O_2 = 2H_2O$$
$$CH_4 + 2O_2 = CO_2 + 2H_2O$$

the approximate theoretical number of c.c.s. of oxygen or air needed for complete combustion can be calculated. To this should be added at least 100% and complete combustion can be assured.

Reverting to the gas analysis in question, shunt the major portion of the residual gas into one of the cuprous chloride pipettes and retain the appropriate number of c.c.s. in the gas burette for explosion. The volume need not be exact to within more or less than 0·5 c.c.s. This volume must then be measured accurately in the usual manner by bringing the reservoir to such a position that the enclosed liquid is on the same horizontal plane with the liquid in the gas burette. (Assume volume of gas is 12·2 c.c.s.).

Oxygen must now be added in the appropriate quantity. This can be conveniently done from an oxygen filled Winchester fitted with rubber stopper and twin glass tubes. The oxygen is extracted by upward displacement with water. Open tap "a" and drop the liquid in the gas burette to about 32 c.c.s. By lifting the reservoir and opening taps "a" and "e" the mixture of gas and oxygen can be transferred to the explosion bulb. Connect the H.T. leads from the induction coil to the platinum contacts and pass a spark. Some books recommend that a thick plate of glass should be placed between the operator and the explosion bulb in case the latter shattered from the force of the explosion. After performing probably several thousand of such explosions the author has never had the misfortune to smash an explosion bulb, but that is no justification for omitting a very simple safety precaution. A cloth or shield of any description is sufficient to ensure that if a bulb should explode, no damage will be suffered by the operator.

After the explosion has occurred, wait a minute for the gases to cool and pass back into the gas burette. Remeasure volume. (Assume 13·3 c.c.s.). Make a further absorbtion in KOH. Remeasure volume and assume to be 9·6. The analysis is now complete and all that remains is a fairly straightforward calculation.

Calculation of Results

1. Difference in volume after first KOH absorbtion :—

$$100 - 97{\cdot}8 = 2{\cdot}2\%\ CO_2$$

2. Difference in volume after alkaline pyrogallol absorbtion :—

$$97{\cdot}8 - 97{\cdot}6 = 0{\cdot}2\%\ O_2.$$

3. Difference in volume after bromine absorbtion :—

$$97{\cdot}6 - 95{\cdot}5 = 2{\cdot}1\%\ C_nH_m$$

4. Difference in volume after absorbtion in cuprous chloride :—

$$95{\cdot}5 - 89{\cdot}6 = 5{\cdot}9\%\ CO.$$

5. The difference between the last two readings of the analysis gives the c.c.s. CO_2 formed by the explosion of the methane.

From the equation :—

$$CH_4 + 2O_2 = CO_2 + 2H_2O,$$

it will be observed that one volume of methane produces one volume of CO_2 thus :—

$$\frac{(13{\cdot}3 - 9{\cdot}6) \times 89{\cdot}6}{12{\cdot}2} = 27{\cdot}2\%\ \text{methane.}$$

6. (*a*) $CH_4 + 2O_2 = CO_2 + 2H_2O$
1 vol. 2 vols. 1 vol. 0 vol.
(*b*) $2H_2 + O_2 = 2H_2O$
2 vols. 1 vol. 0 vol.

From (*a*) it follows that contraction due to the combustion of the methane = twice the volume of the methane.

From (*b*) it follows that contraction due to the combustion of the hydrogen = 3/2 times its volume.

Therefore, contraction in the actual sample = $3/2\ H_2 - 2CH_4$

Therefore, hydrogen = 2/3 (contraction $- 2CH_4$).

This gives the hydrogen in the sample so actual H_2 percentage =

$$\frac{(32{\cdot}3 - 13{\cdot}3 - 2(13{\cdot}3 - 9{\cdot}6) \times 2}{3} \times \frac{89{\cdot}6}{12{\cdot}2} = 56{\cdot}8\%\ H_2$$

The complete analysis of the coke-oven gas is thus given as :—

	%
CO_2	2·2
O_2	0·2
C_nH_m	2·1
CO	5·9
CH_4	27·2
H_2	56·8
N_2	5·6
	100·0

The nitrogen percentage is obtained by addition of all the estimated constituents and their subtraction from 100.

To be continued.

Ageing of Steel

By B. D. Enlund.

THE results of the investigations described in the paper may be summarised as follows :—

All the mild steels examined show ageing after straining. This ageing appears in the form of increasing hardness, yield point and ultimate strength, and in some cases gives rise to brittleness.

The ageing brittleness, particularly, is of practical importance. It shows up differently in different steels and also in one and the same steel in different structural states. Rapid cooling of a steel heated in the γ-field strongly counteracts ageing brittleness, whereas a prolonged cooling time makes the steel brittle, in certain steels immediately after straining, in other cases only after ageing. A comparatively high addition of aluminium in the steel-making process makes the steel less liable to exhibit ageing with regard to hardness as well as to brittleness. The reason for this is not clear, but it might perhaps be connected with the refining action of aluminium on the structure and the grain of the steel.

The investigations presented in this paper have further shown that any mild steel may be prevented from developing brittleness due to ageing, if suitably hardened and tempered, a treatment which should be well suited as a final procedure in the manufacture of various forgings, chains, hooks, etc.

From *Jernk. Annal.*, 1946, **130**, 553–574.

Staff Changes and Appointments

MR. SYDNEY SMITH, M.I.MECH.E., has been appointed Managing Director of The Wellman Smith Owen Engineering Corporation, Ltd., in succession to the late Mr. James Foster-Smith. Mr. Colin J. Barker, Secretary of the Company since its incorporation, has been appointed to the Board of Directors.

MR. LOUIS RIPLEY, O.B.E., whose retirement from the position of Principal Surveyor for Steel to Lloyd's Register of Shipping, was announced in our January, 1947, issue, has joined the Board of Blackett, Hutton & Co., Ltd., Cleveland Steel Foundry, Guisborough, Yorkshire, and will act as their metallurgical consultant.

MR. F. PICKWORTH, Managing Director of the English Steel Corporation, Ltd., has been appointed chairman of Taylor Bros. & Co., Ltd., and Mr. R. G. H. Taylor, formerly assistant Managing Director, has succeeded Mr. T. L. Taylor, who has retired, as Managing Director.

MR. T. H. VARAH has been appointed Resident Technical Representative of Edgar Allen & Co. (South Africa), Ltd., at Johannesburg. He will handle the products of their engineering department, advise on the supply and installation of plant, and supervise the erection and running of Edgar Allen plant in South Africa.

MR. W. BARR, Chief Metallurgist; Mr. R. C. Dymock, Chief Labour Officer; Mr. T. W. Hand, Chief Mechanical Engineer; Mr. J. McCracken, Senior Works Manager; Mr. R. Marshall, Sales Manager; Mr. L. Rothera, Chief Electrical Engineer; and Mr. T. J. Smith, Chief Purchasing Manager, have been appointed Executive Directors of Colvilles, Ltd.

MR. J. N. BRADLEY, B.SC., A.R.S.M., has been appointed Senior Scientific Officer, R.N.S.S., The Admiralty. He is located at the Central Metallurgical Laboratory, Emsworth House, Emsworth, Hants.

MR. FRANK TAYLOR, 113, Amberley Road, Bush Hill Park, Enfield, Middlesex, has recently concentrated his attention to consulting work in the metal finishing field in which he has specialised for many years, having carried out much research and served on several B.S.I. Committees in this field. His experience has been both wide and varied, covering research, production and plant installation aspects and including electroplating of all metals, anodising of light metals, phosphating of ferrous, aluminium and zinc surfaces, and chemical treatments. During the war years Mr. Taylor served as chief chemist of International Corrodeless Ltd., Enfield, and later in the same capacity at J. B. Rushton (London), Ltd. He is regarded as one of the foremost authorities on the various aspects of metal finishing. It is noteworthy that Mr. Taylor is inaugurating an analytical service for electroplating, anodising and phosphating solutions. The object is to assist the small electroplater, unable to maintain a full-time chemist, to keep his solutions in order. It will include recommendations of the necessary basic chemicals. The analysis will, it is understood, be carried out by skilled electrochemists and will be supported by Mr. Taylor's technical and practical experience. Those interested should contact him direct at 113, Amberley Road, Bush Hill Park, Enfield.

SIR CHARLES BRUCE-GARDNER has been appointed Chairman of John Lysaght, Ltd., in succession to Sir Samuel Beale, who wishes to retire from that position. Sir Samuel retains his seat on the Board of Directors. The President of the Board of Trade has agreed to release Sir Charles Bruce-Gardner from his position as Chief Executive for Industrial Conversion, which he has held since 1944, but his services will continue to be available in a consultative capacity on such general industrial matters as may be submitted to him by the Board of Trade.

MR. STANLEY ROBSON, M.Sc., has been appointed Consultant to the Imperial Smelting Corporation, Zinc Corporation, and New Broken Hill Consolidated.

MR. HUGH D. MALLON, B.Sc., A.R.T.C., has been appointed a member of the lecturing staff of the Military College of Science, Shrivenham, Wilts.

MR. N. F. ASTBURY, M.A., F.INST.P., A.M.I.E.E., has been appointed Director of Research to the Guest, Keen & Nettlefolds group of companies. Mr. Astbury was Director of the Research Laboratories of Joseph Sankey & Sons, Ltd.—one of the member firms of the G.K.N. group—whose new laboratories were officially opened last year. It is intended that these laboratories shall now become the headquarters of the research organisation of the combine.

MR. O. INMAN, Chief Engineer of Samuel Fox & Co., Ltd., has been appointed a Director of the Company.

MR. R. H. MYERS, Assoc. Met. (Sheffield), F.I.M., has been appointed Head of the Steel Making Division of B.I.S.R.A., and Dr. A. H. Leckie, B.Sc., Ph.D., F.R.I.C., has been appointed Deputy Head.

Mr. Myers studied under Professors J. O. Arnold and A. MacWilliam at Sheffield, and, after a post-graduate course of one year, started his industrial career with the Midland Iron Company, engaged in the manufacture of wrought iron. After working in the laboratories at Steel, Peech & Tozer, he worked his way through the acid steel making department at that works and progressed from assistant manager to manager. Since 1930 he has been associated with research in the steel industry, as Open Hearth Officer to the Iron and Steel Industrial Research Council, in addition playing an active part in the Corrosion and Heterogeneity Committees set up jointly by the Research Council and the Iron and Steel Institute. He continued in this capacity until the formation of B.I.S.R.A., from which time he has been Acting Joint Head of the Steel Making Division.

Dr. A. H. Leckie studied chemistry at University College, London, under Professors F. G. Donnan and C. K. Ingold. After graduating he was engaged in research for several years on the subject of molecular spectroscopy on which he published numerous papers. In 1937 he joined the technical department of the British Iron & Steel Federation and was engaged in research on Iron and Steel Works plant and principally on open hearth furnaces. Dr. Leckie joined B.I.S.R.A. when that body took over the work of the Federation Technical Department and is in general charge of the Division's research work on furnace design and operation.

The Institute of Metals

Annual General Meeting held in London

Considering the difficulties encountered, particularly the severe weather conditions which seriously interfered with transport, this meeting was reasonably well attended. In addition to the technical sessions, several works visits were included, and the annual dinner and dance was restored, all of which proved to be successful and a welcome return of peace-time facilities for meeting new and old members. Here, brief reference is made to the initial meeting and to the papers presented at the technical sessions.

THE thirty-ninth annual general meeting of the above Institute was held in the Halls of the Institution of Civil Engineers and the Royal Institution of Chartered Surveyors, in Great George Street, London, S.W. 1, on March 5th to 7th, 1947, Colonel P. G. J. Gueterbock, C.B., D.S.O., M.C., T.D., D.L., J.P., M.A., President, occupying the Chair. In opening the meeting, the President said it had been hoped that this first peace-time annual meeting would be attended on a scale worthy of the Institute, but the weather proved a deterrent. He extended a welcome to all attending, and referred especially to Service members and those who have returned to peace-time work. Many overseas members were expected, and a welcome was extended to Dr. Röhner, of Switzerland.

Report of Council

The ban on the publication of periodicals prevented the distribution of this Report in advance of the meeting and, therefore, members were unable to study it before the meeting, it was, therefore, taken as read, but the President referred briefly to the not unsatisfactory record of the activities of the Institute, in spite of the rather difficult period of post-war adjustment which is not by any means at an end. Much has been done, but much remains to be done, for a live Institute must ever press on progressing continuously to meet the needs and assist the industries it serves.

Particular mention was made of the latest position with regard to the Mond Nickel Fellowships. The foundation was announced twelve months ago, and the legal documents have been approved by all the five operating societies and by the Mond Nickel Company. The formality of signature will be completed in the very near future, and an announcement will be made shortly together with an invitation for applications for Fellowships with a view to awarding at least one or two during the current year.

Election of Officers for 1947–48

As no other nominations had been received, those nominated at the autumn meeting of this Institute to fill vacancies among the honorary officers and on the Council for 1947–48 had been elected. as follows:—

President: Col. P. G. J. Gueterbock, C.B., D.S.O., M.C.

Vice-President: Mr. J. Cartland, M.C., M.Sc.

Members of Council: Prof. Leslie Aitchison, B.Sc., D.Met.; Mr. John Arnott; Dr. Maurice Cook, M.Sc.; and Mr. A. J. Murphy, M.Sc.

Sir Clive Baillieu, Dr. Gwyer and Dr. Sykes retire by rotation from the Council, and Mr. G. L. Bailey retires as vice-president, but the services of the latter will be retained, because he has been appointed to the Council as representative of the Institution of Metallurgists.

May Lecture

The May lecture has been arranged to be given on May 21st, at 6 p.m., in London by Sir Wallace Akers, K.B.E., Director of Imperial Chemical Industries. The subject will be connected with atomic energy and the peaceful application of nuclear energy. It is proposed that the following day should be devoted to a discussion of papers.

The Future of the Institute

In his Presidential Address last year, Col. Gueterbock said his intention was to provoke thought rather than to suggest any definite plan to increase the value and scope of the Institute. He did so because he realised that any plan which was to be successful must embody the general desires of members, and, indeed, the whole of the metallurgical community, both industrial and scientific. In pursuance of this object he has visited each of the local sections and has been stimulated by the discussions, which included a great deal of valuable and constructive criticism and many well-thought-out practical suggestions. The main points which have emerged include: suggested improvements in the Institute's journal, ways in which the local sections could be helped to a greater degree, and a broadening of the services rendered, with the object of serving the whole metallurgical community.

With regard to keeping in touch with members overseas, it was announced that Mr. G. L. Bailey is in the United States representing the Institute at the meeting celebrating the seventy-fifth anniversary of the American Institute of Mining and Metallurgical Engineers. In addition, Dr. C. H. Desch, President of the Iron and Steel Institute, will also attend to represent British metallurgical interests.

Award of the Institute's Platinum Medal

The award of the Platinum Medal jointly to Dr. J. L. Haughton and Mrs. Haughton (Dr. Marie Gayler) is unique, in that a husband and wife are both fully qualified to receive and deserving of the high honour of the non-ferrous metallurgical world. Both are well known as a result of their brilliant scientific work, chiefly connected with the structure of light alloys.

In making the award, Col. Gueterbock said that seldom, if ever, can such intellectual accord have existed between husband and wife and have led to such important scientific results. We hope that Dr. and Mrs. Haughton may both live to enjoy for many years the well-deserved leisure which they have now achieved.

On behalf of Dr. Gayler and himself, Dr. Haughton thanked the President, Council and members for the great honour conferred upon them, an honour of which they would feel unworthy but for the fact that in making the award it was also being made to the Metallurgical Department of the National Physical Laboratory. In mentioning that Department he referred particularly to the late Dr. Walter Rosenhain, whose genius, energy and, perhaps more than anything else, his enthusiasm, which initiated the work and led to the conferment of this honour. He also mentioned the names of Professor Turner and Dr. Hudson to whom they both owed a great debt.

Technical Sessions

Two technical sessions were held at which some eight papers were presented for discussion. At the first session there was a joint discussion of those papers dealing with the hot-shortness of some aluminium alloys, followed by a paper on the influence of composition on the adhesion of tin-base bearing alloys to steel and the effect of iron and silicon impurities on aluminium—10% magnesium test bars. At the second session were discussed the selective corrosion of phosphor-bronze in hot-water service, magnesium-cerium-zirconium alloys and reduction of the iron content of magnesium-base alloys. It is only possible here to give brief summaries of the various papers.

HOT-SHORTNESS OF ALUMINIUM-SILICON ALLOYS OF COMMERCIAL PURITY

By A. R. E. Singer, B.Sc. and P. H. Jennings, B.Sc.

THE hot-shortness of the commercially-pure aluminium-silicon alloys has been studied by means of casting and welding experiments. Castings were made in an annular mould in which stresses were set up by contraction during cooling. The whole process of solidification of an alloy could be observed visually. The pouring temperature of the metal was maintained throughout the experiments at 100° C. above the liquidus. A cast-iron mould was used and kept at a temperature of approximately 150° C., but the mould temperature was found not to be critical. The results show the severity of cracking to increase sharply with the addition of silicon to a maximum of 0·7% and to decrease rather less rapidly, reaching zero at about 3% silicon. The cracks ranged in size from fine hair cracks to those extending from top to bottom of the ring and affecting the whole section. The fine cracks were most numerous on the top surfaces of castings in alloys containing 1·5 and 2·0% silicon, where they accounted for most of the cracking. The maximum scatter of the results occurred in the 0·6% silicon alloy in which the extreme limits of 14 values were lengths of 4·5 and 8·9 in.

Welding tests on the alloys were roughly divided into two groups in which: (1) a complex shape or structure is welded; and (2) a restrained weld is made between two sheets clamped rigidly in a massive frame. Cracking tended to occur preferentially at the point of finishing of the weld, especially when the reinforcement at this point was insufficient. Most of the cracking was at the centre of the weld bead, and tended to be more extensive on top than beneath.

As a result of this investigation, the authors conclude that in commercially-pure aluminium-silicon alloys containing approximately 0·2% iron, there is a hot-short composition range extending roughly from 0·25–3% silicon. No appreciable hot-shortness has been found in super-pure aluminium nor in alloys containing more than 3% silicon. The greatest degree of hot-shortness occurs in alloys containing 0·7–0·8% silicon, and this probably coincides with the effective solid solubility limit pertaining to the conditions of experiment.

Castings and welds made in alloys within the hot-short composition range are subject to cracking during solidification if free contraction is prevented. The compositions of the most frequently used commercial alloys of aluminium with silicon lie beyond this range, but an undue amount of silicon in commercial aluminium makes it hot-short and may cause much trouble during welding.

HOT-SHORTNESS OF SOME ALUMINIUM-IRON-SILICON ALLOYS OF HIGH PURITY

By A. R. E. Singer, B.Sc. and P. H. Jennings, B.Sc.

RESEARCH has been carried out on the hot-cracking tendencies of castings and welds in the aluminium-iron-silicon alloys, by means of laboratory tests. A restrained-weld test has been used on alloys containing up to 0·6% silicon and 0·5% iron, and a more extensive range of alloys has been investigated by means of a casting test.

The results have shown that there is a large measure of correspondence between the casting and welding properties, and it seems that the term hot-shortness can be used to include both. As the percentage of silicon increases, the amount of cracking increases sharply to a maximum and then decreases to a low value. The effect of iron is to delay the onset of cracking, to reduce the severity of cracking at the maximum, and to push the position of the maximum to a higher percentage of silicon. These results have been embodied in two ternary diagrams. Both in castings and welds the cracks are intercrystalline and are formed at a high temperature.

The important conclusion is that when commercially pure aluminium is to be cast or welded in conditions where contraction stresses may arise, the silicon content should not exceed the iron content.

PROPERTIES OF THE ALUMINIUM-SILICON ALLOYS AT A TEMPERATURE IN THE REGION OF THE SOLIDUS

By A. R. E. Singer, B.Sc. and S. A. Cottrell, B.Sc.

A PARTICULARLY troublesome property encountered in the casting and welding of aluminium alloys is that of hot-shortness, and, in order to obtain information likely to assist in explaining the mechanism of this property, the tensile properties of the aluminium-silicon alloys have been determined at temperatures in the region of the solidus.

The tensile strengths of aluminium-silicon alloys containing up to 12% of silicon show a gradual decrease as the temperature increases above 400° C. to finite values at the solidus temperatures. The steepness of the curves increases with increasing silicon content, but

up to the solidus temperature the elongation and reduction of area of all the alloys remain high. At the solidus temperature, elongation and reduction of area decrease to zero and the strength rapidly decreases to a very low value. The alloys retain this small strength, or coherence, up to a temperature intermediate between that of the solidus and liquidus. The temperature range above the solidus over which the alloys are coherent is dependent on their chemical composition, and in conditions approaching equilibrium increases to a maximum at approximately 1·8% of silicon and then decreases to a small value at higher percentages of silicon.

By micrographic investigation, it has been possible to link the tensile properties at temperatures in the region of the solidus with the aluminium-silicon equilibrium diagram.

It appears that the extent of the temperature range above the solidus over which the alloys possess a finite strength yet have no appreciable ductility may be one of the principal factors determining their hot-shortness characteristics.

THE INFLUENCE OF COMPOSITION ON THE ADHESION OF TIN-BASE BEARING ALLOYS TO STEEL

By P. G. Forrester, M.Sc. and L. T. Greenfield, M.Sc.

WHEN a tin-base white-metal lining is cast on to steel by the ordinary hand-lining method, the quality of the adhesion has been shown to depend on the composition of the white-metal. In particular, alloys of high copper content have low-bond strengths owing to a tendency for Cu_6Sn_5 to form on the bond. This segregation of Cu_6Sn_5 is due to a combination of directional cooling and of the provision of nuclei for crystallisation by the tinned steel surface, and it may be wholly or partly inhibited by very rapid cooling. Bonds as strong as the white-metal itself can be obtained with tin-antimony-copper alloys with up to 3·5% copper. With alloys containing 7% copper a layer of Cu_6Sn_5 may form at the bond and reduce its ductility and resistance to shock. Either the chisel test or the test described by Chalmers indicates this type of bond weakness, which is not shown, however, by a pure shear test. A thick layer of $FeSn_2$, formed by prolonged immersion in a tin bath at high temperature, weakens the bond in a similar manner.

The addition of cadmium to tin-antimony-copper alloys has been shown to increase their hardness, tensile strength, fatigue strength and resistance to pounding. It has been suggested, however, that cadmium may impair bonding qualities and the effect of cadmium on the adhesion of tin-base white-metals to steel has been studied. The results of tests indicate that a good bond can be obtained with tin-base alloys containing up to 3% cadmium provided that slow cooling is employed. Rapid cooling gives low-bond strength in the cadmium-containing alloys, in contrast to its favourable effect on the adhesion of cadmium-free alloys. In the latter, rapid cooling is favourable to adhesion because it supresses Cu_6Sn_5 formation at the bond and tends to prevent the formation of shrinkage cavities. In the cadmium-containing alloys these favourable tendencies are probably nullified by the effect of differential contraction. Having a much higher creep strength than cadmium-free alloys, those containing cadmium cannot absorb this contraction so readily by rapid creep and cracks form with high rates of cooling.

EFFECT OF IRON AND SILICON IMPURITIES ON THE TENSILE PROPERTIES AND HEAT-TREATMENT CHARACTERISTICS OF SAND-CAST ALUMINIUM.

By R. T. Parker, Ph.D., B.Sc., A.R.S.M., G. M. L. Cox, B.A., and A. N. Turner, B.Sc., A.R.S.M.

THE successful application of aluminium and its alloys to the manufacture of engineering parts involves the recognition of the specialised technique involved in their fabrication and the characteristic properties associated with this class of materials. This is especially true of the aluminium-magnesium alloy, containing nominally 10% magnesium, which has remarkable tensile properties and high resistance to corrosion. The specified minimum mechanical properties of test bars in this alloy to specification D.T.D. 300A cast in dry sand, are: ultimate tensile strength, 16 tons/sq. in. and elongation 7% on 2 in., but it has been found that values far in excess of these minima can be obtained. The chief disadvantages of these aluminium-base alloys are in the difficulties caused in working, and particularly in casting, by the presence of magnesium.

Results of tests have shown a wide range of ultimate tensile strength from about 14–23 tons/sq. in., and since the possibility of obtaining strengths of 23 tons/sq. in., coupled with high elongation, from a sand-cast alloy is attractive, an investigation is described in this paper to determine under what conditions consistently high values for the properties are realisable with the aluminium alloy containing 10% magnesium. Groups of D.T.D. test bars were cast in dry sand from melts containing 0·10–0·75% iron with 0·10–0·50% silicon. It was found that while an increase of iron has a slightly beneficial effect, an increase of silicon drastically reduces the ultimate tensile strength and elongation. The proof-stress value is slightly increased with increasing total impurity content.

The optimum tensile properties of an alloy containing 0·10% iron and 0·10% silicon appear to be approximately 25 tons/sq. in. ultimate tensile strength and 35% elongation on 2 in., these values being obtained from test bars solidified under an air pressure of 100 lb./sq. in.

A comparison of low- and high-purity aluminium—10% magnesium-alloy test bars under varying heat-treatment conditions showed that the high-purity alloy is much the more sensitive to differences in solution, time and temperature.

THE SELECTIVE CORROSION OF PHOSPHOR-BRONZE IN HOT WATER

By W. D. Clark, M.A., M.Sc.

PHOSPHOR-BRONZE pump impellers handling hot feed-water and condensate on a power station have been found to be suffering from a form of attack analogous to dezincification. The feed-water consists of zeolite-softened make-up and returned condensate, and is treated with caustic soda, bisulphite and disodium phosphate, the last named added at intervals. The condensate contains only a little carbon dioxide and has a pH near 6·0, except when a heater leaks, in which case the condensate from that heater contains feed-water

and is alkaline. The feed-water system consists of a series of four pumps, from the last of which the water is delivered at a pressure of 1,100 lb./sq. in., and seven heaters in which the water is heated to a final temperature of 200° C. by steam bled at suitable pressures from a feed-head turbine. The condensate which is formed in each of these heaters is drawn off by a separate heater extraction pump and injected into the main feed line as it leaves the heater.

Micrographic, analytical and X-ray evidence of the nature and products of the attack is presented in this paper, and it is concluded that the attack is by selective solution analogous to dezincification and that solution and redeposition is almost certainly involved. A very great difference has been noted between the damage done to two surfaces of the same piece of metal, that at a machined surface being greater than that at "as cast" surfaces. This has resulted from having exposed the pores in the metal to ingress of liquid, and attack throughout their depth. Had neither surface been machined or had the metal been free from appreciable porosity the amount of attack would not have been very important. On the "as cast" surface the attack has progressed in a complex manner leaving a number of lamellar residues.

MAGNESIUM-CERIUM-ZIRCONIUM ALLOYS: PROPERTIES AT ELEVATED TEMPERATURES

By A. J. Murphy, M.Sc. and R. J. M. Payne, B.Sc.

A SHORTCOMING of magnesium-base casting alloys, which has limited their fields of application, has been their tendency to creep, under small loads at elevated temperatures. While the practical effects of a poor resistance to creep may, in certain cases, be reduced to negligible proportions by suitable design, there remains the need for a magnesium alloy having improved characteristics at elevated temperatures. The object of the investigation described in this paper was to establish such an alloy, and thus to make possible further economy of weight in stressed light-alloy castings operating at elevated temperatures.

TABLE I.—Composition of Alloys Used for Exploratory Tests

Alloy	Composition %			
	Cerium	Zirconium	Calcium	Magnesium
A	3·01	—	—	remainder
B	3·5*	—	0·125*	"
C	3·10	0·46	—	"
D	1·81	0·47	—	"

* Nominal.

Four alloys, of the compositions given in Table I, were prepared from the magnesium stick, "Mischmetall," and a magnesium-zirconium alloy containing 0·65% zirconium. The calcium was added as a magnesium-calcium alloy containing 40% calcium. The approximate composition of the "Mischmetall" is given as:

Carbon	Silicon	Iron	Cerium	Other rare-earth metals
trace	0·03–0·13	0·3–4·0	53·5	remainder,

Tests show that the magnesium-cerium alloys containing about 3% cerium possess good strength and resistance to creep at 200° C. They are not hot-short or liable to serious shrinkage troubles, and cast well in sand moulds. Their mechanical properties at ordinary temperatures, however, are poor.

By the addition of zirconium, alloys are obtained which have mechanical characteristics at room temperature comparable to those of the usual casting alloys Elektron A8 and AZ91 (specifications D.T.D. 59A and 136A), but possessing resistance to creep of a far higher order. When tested at 200° C., the creep-resistance of certain of the magnesium-cerium-zirconium alloys is very little inferior to that of the widely used aluminium alloys of the type covered by specifications D.T.D. 133C and 287. The combination of good casting qualities and good mechanical properties at ordinary and elevated temperatures makes the magnesium-cerium-zirconium alloys attractive for some important light-weight stressed components of engines, for which magnesium-base materials have hitherto been unsuitable.

The good creep-resistance of the magnesium-cerium-zirconium alloys is shared by the quaternary alloys formed by the addition of such elements as zinc and silver.

SOME FACTORS IN THE REDUCTION OF THE IRON CONTENT OF MAGNESIUM-BASE ALLOYS

By F. A. Fox, M.Sc., C. J. Bushrod, M.Sc., and S. E. Mayer, Ph.D.

IN making 2-ton melts of the standard magnesium-aluminium containing alloys conforming to D.T.D. Specifications 59A and 136A, it was observed that although ingots produced in the early stages of casting had an iron content of 0·025% there was some variation of iron content in the ingots cast later. Analyses of ingots showed that the iron content progressively decreased from the beginning to the end of the pouring operation. Observations appeared to show that appreciable setting of manganese and iron occurred during the normal production melting cycle, and it seemed that it might be possible to control setting in such a way as to produce metal of low iron content by fairly simple modifications of existing melting-shop technique, and, at the same time, to throw light on the mechanisms involved. With this object, experiments were carried out, first on a small laboratory scale and the on a full-production scale, in which the results of the smaller scale experiments were applied.

The results show that the iron content of magnesium-aluminium alloys can be reduced by means of settling with manganese, even when melting in iron-rich crucibles. The efficiency of the process depends on three main factors:—

1. The addition of a sufficiency of manganese, in a suitable form.
2. The use of suitable settling conditions which, from a consideration of the small- and full-scale experiments, implies the use of crucibles of such depth to diameter ratios and heating conditions as are designed to reduce convection effects.
3. The use of crucibles having small wall-area to metal-volume ratios (i.e., the use of large-capacity crucibles) to reduce iron pick-up.

It was found that the speed of pick-up of iron increases with increasing manganese content, but that the solubility of iron in the magnesium-aluminium alloys is decreased by an increase in manganese content. The authors consider it is most probable that the iron is removed by manganese-rich particles in the melt which settle out together with iron. Three mechanisms which would possibly account for the observed results are:

(*a*) Crystallisation of the manganese-aluminium compound on iron nuclei or, alternatively (but much less likely) iron on the compound nuclei.

(*b*) Co-precipitation of iron and manganese as their respective aluminium compounds or as ternary or more complex compound.

(*c*) Partition of iron between the magnesium-rich phase and the manganese-rich phase.

The possibility that simple manganese-magnesium compounds might be formed has not been considered, as Bulian and Fahrenhorst have produced evidence that no compounds of this type are formed in the magnesium-aluminium-manganese* system.

The association of high iron contents with high manganese contents would be expected if any of the above mechanisms were operative, so that this observation does not assist in discriminating between them. The solubility of iron in manganese at temperatures less than 850° C. is about 30%, so that the process (*c*) might proceed by adsorption of iron on the manganese particles or by true solution of iron in the manganese.

A melting cycle has been developed which was found successful for the alloys containing aluminium, with which it has been tried in the consistent production of ingot containing <0·002% iron. It was found, however, that the binary magnesium-manganese alloy (Elektron AM503) could not be produced in this way with a low iron content.

It is probable that, as manganese particles settle through the melt, the rate of removal of iron depends on the number of the particles and also on the concentration of iron in the metal. However, as the manganese particles pick up iron they will probably show less tendency to pick up more iron, and if this is so, it would be expected that greater efficiency in removal of iron could be achieved by adding a given quantity of manganese in two portions, in successive settling operations rather than making the addition in one operation. This possible "loading" effect of the manganese particles is amply supported by results which have been obtained in settling experiments using a simple recycling process.

It was thought that manganese particles in metal taken from the bottom of settled melts might differ in structure from those in metal taken from the top of the melt, on account of the iron associated with the settled manganese. On examining suitable specimens at magnifications up to 1,000 dia., however, no structural differences could be detected; this suggests that a mechanism of true solution of iron in manganese operates.

The authors have concluded that economical production of Elektron AM503 of low iron content is impracticable by any manganese settling process, and that other iron-precipitating agents would have to be used. The use of the manganese as metal rather than as manganese chloride for alloying is desirable for maximum corrosion-resistance, as in the former case very many fewer manganese-rich particles are produced.

It appears that when melting in ferrous pots less pick-up of iron is to be expected from contact of the melt with decarburised surfaces than from contact with those containing carbon. This decarburisation was found to be accompanied by some pick-up of aluminium and magnesium in the melting of the magnesium alloys containing aluminium, and that this pick-up is quite pronounced in the case of high-manganese steels. It is suggested that either (*a*) this pick-up, owing to its "sealing" effect on the steel surface, greatly retards dissolution of iron in the molten magnesium alloy, or that (*b*) such dissolution is also accompanied by a dissolution of manganese from the crucible wall, which will provide a local supply of precipitant for this iron as quickly as it is dissolved. If the former mechanism holds, definite advantages can be expected from the use of manganese steels in all conditions; if the latter, there will be an advantage only above a certain limiting temperature, since it has been found that the presence of high concentrations of manganese in the magnesium also promotes dissolution of iron, and that at lower temperatures this effect more than outweighs the accelerated iron-precipitating tendency associated with the presence of the higher manganese concentration.

* The present authors' X-ray examination of residues from Elektron AM.503 melts has given no indication that iron is present in any form other than that of alpha iron.

Welding the New House of Commons

It will be remembered that the House of Commons was among a number of famous buildings damaged by bombs during the blitz of 1940–41, and the rebuilding is now in progress to the design of Sir Giles Gilbert Scott, O.M., R.A. Welding, in conjunction with black bolting is being used for site connections to the structural steelwork in order to eliminate the noise which is inseparable from rivetting. The only alternative was to use fitted bolts which was ruled out on account of their cost.

The consulting engineer for the work is Oscar Faber, O.B.E., D.C.L., D.Sc., M.Inst.C.E., M.I.Mech.E., etc., who was one of the first engineers to use welding on a job of large magnitude in this country—the Bank of England. This work was done prior to the existence of any regulations governing such methods and it is probable that it had an influence both on the relevant British Standards Specification No. 538 first issued in 1934 and on the L.C.C. Welding Regulations which were published shortly afterwards.

Messrs. Redpath Brown & Co. Ltd., of London, have been appointed steelwork sub-contractors for this work. They are alive to the progress which welding has made during the war years, and it is understood that a part of their shops in East Greenwich has been modified to meet the requirements of welded fabrication, and that ample room has been left for future expansion.

All the welding operators who will work on this contract have been given a special test on the particular types of joints which they will be called upon to make and with due regard to the welding position to be employed. Full size tests on the particular type of joint to be used on the structure were also made and demonstrated: (1) That the black bolts in conjunction with welding gave an increased strength of joints; (2) that the welding by itself would give an ample factor of safety.

As most of the welding is to be done in the vertical position, electrodes specially suitable for this condition have to be used and the "Vodex" type was chosen. These are being supplied by Murex Welding Processes, Ltd., who also carried out the testing of the welders on behalf of the consulting engineer.

The Nickel Bulletin

The December, 1946, issue of the *Nickel Bulletin* contains a subject index to Volume 19 as well as many interesting abstracts. Among these, there is considerable material on electro-polishing and electrodeposition, together with useful data on cast irons. The *Nickel Bulletin* is obtainable free of charge from The Mond Nickel Company, Ltd., Grosvenor House, Park Lane, London, W.1.

Electric Drives to Recovery

Mill Motors to Increase Production

THE need for increased production of improved products is greater to-day than has even been experienced, and the need is universal: it is imperative, therefore, to apply all possible means to meet demands so that progress can be achieved. The shortage of man power is one of the most important factors delaying recovery, but by improving the equipment as well as the materials employed, or the technique involved in the manufacturing processes, and by taking advantage of the best research facilities available, much can be done to speed up production with existing manpower. In improving technique many notable achievements have been accomplished in mechanical progress, from the raw material to the finished article. In these developments the use of electricity is having an important influence: improved designs in motors and controlling devices, for instance, are contributing to speedier production.

The preoccupation of industry in reconversion to a peacetime basis and in expansion to meet the needs of the drive for exports, has been reflected in an unprecedented demand for small and medium-sized motors. Indeed, so great is the demand that in one instance—Metropolitan-Vickers Electrical Co., Ltd.—a large factory, previously engaged in the manufacture of Lancaster bombers, has been taken over for their manufacture. Although this Company reports few changes in design, constant attention has been given to the improvement of manufacturing processes and the use of new materials.

The sealing of the windings of ordinary general-purpose motors against moisture and the treatment of motors for use in tropical climates have been studied intensively, and new impregnating facilities have been installed. The advantages of providing the highest grade of insulation on the windings of motors and generators is well appreciated, and several new materials have been under investigation. Woven glass insulation in conjunction with suitable varnishes has become firmly established for many applications.

The experience gained on special work has had an important influence upon the more orthodox machines. For instance, a 133⅓ cycle, 500 volts, a.c. motor of relatively small dimensions had an output of 200 h.p. at 8,000 r.p.m.; as a direct result of building this machine several major changes have been made in the design of the more usual high speed (3,000 r.p.m.) motors. Typical of new applications is the supply of a.c. totally enclosed fan-cooled motors rated at 1,000 h.p. at 3,000 r.p.m. for direct-on starting, this necessitating a particularly robust construction.

For the wire drawing industry again, large numbers of wide speed range, forced ventilated, d.c. motors suitable for heavy dynamic braking have been supplied for use on multiple drive wire-drawing machines: these motors are flange mounted and are designed so that they can be built into the main body of the machine. While in the steel industry there has been a large demand for Metrovics special d.c. steelworks auxiliary motors. Similar motors designed strictly in accordance with the standardised dimensions of the American Iron and Steel Institute are also being manufactured. A large proportion of the transmission equipment has been for overseas markets, but notable trends have been the heavy demands for equipment to increase the capacity of British plants and none more than the iron and steel industry as will be noted in connection with rolling mills.

Rolling Mill Equipment

The outstanding feature of rolling mill work has been the number of reversing mill equipments designed to replace steam engine drives of primary mills. In all, ten are being built or have been installed.

Two reversing equipments have been put into operation at the Cargo Fleet and West Hartlepool Works of the South Durham Iron and Steel Co., one driving a 32-in. section mill finishing end and the other a 10-ft. plate mill. A third, for a 40-in. blooming mill at the Cargo Fleet Works, is nearing completion. These three equipments are duplicates of one another, and of a fourth supplied in 1935 for a 33-in. universal slabbing mill. Each comprises a 5,000-h.p. R.M.S. mill motor, running at 54/150 r.p.m. and capable of operating peaks equivalent to 14,000 h.p. and emergency peaks of 15,500 h.p., and is complete with its motor-generator plant.

John Summers & Sons, Shotton, have been supplied with equipment for an 80-in. reversing, cold-strip mill, consisting of a 2,500-h.p. 93/186-r.p.m. d.c. motor, direct connected to the rolls; two 1,000-h.p. 200/675-r.p.m. motors driving reels on each side of the mill; and a motor-generator set with a 3,000-kVA, 6,600-volt synchronous motor, driving a 2,200-kW generator and two 456-kW boosters. By means of Metadynes controlling the fields of the two real motors, practically constant tension is maintained during both winding and unwinding the reels.

Work is in hand on blooming and structural mill equipment for the rehabilitation of the Appleby-Frodingham plant at Scunthorpe. The Metropolitan-Vickers Company has undertaken the layout of the whole of the sub-station, and the contract includes 33-kV switchgear, outdoor transformers, 6·6-kV and low tension a.c. switchgear, d.c. switchgear and two reversing mill equipments complete. One equipment is of 5,500 h.p. at 40/90 r.p.m., and the other of 5,000 h.p. at 50/120/140 r.p.m. The motors are capable of normal peaks of two and a half times full load and emergency peaks of three times full load. They are supplied by flywheel motor generator sets, driven by 4,000-h.p. induction motors with a flywheel having a stored energy of 175,000-h.p. secs. to equalise the peaks on the supply mains through an automatic slip regulator. The main sub-station will house all the electrical equipment except the mill motors.

In addition to these large equipments, there are a number of installations of 1,000 h.p. and less for mills of various types throughout the country.

THE approaching Centenary Celebrations of the Chemical Society prompt some reflections on appropriate ways of signalising this landmark in the history of British Chemistry. There has been in recent years much talk of closer collaboration between the existing societies. Is there no possibility that some move might be made to use the coming Centenary as a means to this end? We cannot claim, quoting chapter and verse, that the American way of chemical organisation is better than ours, but we cannot, at the same time, avoid the feeling that much organising ability is dissipated in this country by the multiplication of the need for it which arises from the many societies. Following the American pattern, then, to take the example which most nearly concerns us, the Society of Public Analysts and Other Analytical Chemists, with its Groups, would form the basis of the Analytical and Microchemical Section of this unified British Chemical Society. (In passing, we would venture the comment that some title such as this would indicate to the inquirer more fairly the true function of this particular body, the more especially since the present Society is most often referred to by its shortened and somewhat misleading title). The present Chemical Council goes some way towards the fusion of effort that we envisage. Undoubtedly, further unification will ultimately be forced upon us even if we do not work consciously for it. To those who doubt that this year, rather than next year or ten years hence, is the time for the move, we would merely quote the most potent argument in its favour—that in unity is strength.

Applications of the Polarograph to Metallurgical Analysis

II.—Polarographic Methods for the Determination of Zinc in Copper Base Alloys

By G. W. C. Milner

Chemistry Department, University College, Hull.

It was found impossible to determine zinc in copper base alloys directly by polarographic methods because of the interference of the large diffusion currents due to copper ions. In this paper three methods of separating copper and zinc are described, together with the reactions of other alloying elements generally present in brasses and bronzes. Precipitation of the zinc from the copper in bronzes by sodium sulphide from an alkaline cyanide medium is recommended when the alloy contains a high percentage of nickel, otherwise potassium iodide is used to remove the bulk of the copper as cuprous iodide.

The zinc-sulphide precipitation method is recommended for brasses because of the large amounts of alloying elements generally present in these alloys; this procedure removes the zinc from most of these elements. For traces of zinc in bronzes the copper is more completely removed from the zinc by using hydrogen sulphide. In all cases the zinc is finally determined polarographically using an ammonia-ammonium chloride base electrolyte.

Introduction

THE conventional methods for determining zinc in bronzes (Zn content up to 6%)[1] consist of precipitating the zinc either as sulphide or as phosphate, from the ammoniacal filtrate which remains after removing all other metals normally present in bronzes, from solution. The precipitates are filtered off and ignited to the oxide or pyrophosphate respectively

Alternatively, the zinc can be precipitated as sulphide by passing hydrogen sulphide into the filtrate after the removal of Group 1 and 2 metals, and after adjusting the solution to a faint acidity. The precipitate is again ignited to the oxide. These methods give accurate results but are slow because of the necessity to precipitate and filter off the interfering metals. More

1 British Chemical Standards, Certificates of Analyses of Bronze "A" and Bronze "C" (207) issued by the Bureau of Analysed Samples, Ltd., Nr. Markington, Harrowgate.

recently, a rapid method for the determination of zinc in bronzes containing from 1·0 to 2·0% zinc has been developed,[2] in which the zinc is selectively precipitated with 8-hydroxyquinoline in the presence of all the other metals.

Similarly, in brass analysis (Zn content 20 to 40%), the zinc is determined, after the removal of all other metals from the solution, by precipitating as the sulphide or phosphate.[3] The zinc sulphide is ignited to the oxide which can be weighed, or dissolved in acid and the determination finished electrolytically, or by titrating with potassium ferrocyanide. Because of the high percentage of zinc in brasses it is difficult to wash it out completely from some of the more gelatinous precipitates of the interfering metals. Therefore, to obtain accurate results, reprecipitations must be carried out and the zinc traces added to the main zinc filtrate. All this materially increases the time taken for the zinc determination and so a study of polarographic methods of analysis was made with the aim of developing rapid methods for determining zinc in copper base alloys.

Preliminary Considerations

A study of the current literature shows that zinc gives a well-defined polarogram in a variety of base electrolytes, ranging from moderate acidity to strong alkalinity.[4] Unfortunately, in these base electrolytes, copper gives a curve having a more positive half-wave potential than the zinc curve. The method of suppressing the copper curve, by complex ion formation with KCN, is not applicable in zinc determinations because of the formation of a zinc cyanide complex, with a half-wave potential outside the normal polarographic working region. Therefore, direct polarographic methods for the determination of zinc in copper base alloys in the presence of the main constituent appear impossible from the current literature.

The polarographic interference of copper must be removed and so chemical separations were investigated. The following two methods are possible :—

(1) The complete precipitation of the zinc and removal from the copper by filtration.

(2) The precipitation and removal of the bulk of the copper leaving the zinc completely in solution.

Both these lines of investigation have been pursued and this paper is based on the results obtained. After the removal of the copper interference, the base electrolyte considered most suitable for the zinc determination consisted of 200 ml. ammonia (sp. gr. 0·88), 200g. ammonium chloride, 200 ml. 2% gelatine solution in water, and 1,600 ml. of water (base electrolyte A). This medium gives an excellent polarogram for zinc having a half-wave potential of about −1·10 volts vs. the mercury pool anode.

Determination of Zinc in Bronzes

The complete precipitation of the zinc in bronzes and its removal from almost all the copper was first investigated. It had previously been noticed, when investigating polarographic nickel determinations in brasses and bronzes, that zinc was quantitatively precipitated by sodium sulphide from an alkaline cyanide medium.[5] Further investigations with this precipitation led to the following method for the determination of zinc in bronzes :—

Method 1

Dissolve 2·0 g. bronze in 25 ml. nitric acid (sp. gr. 1·20) and boil out the nitrous fumes. Cool and make the volume of the solution up to 100 ml. Pour a quantity through a dry Whatman No. 40 filter paper into a dry beaker to remove metastannic acid. Pipette 25 ml. of the filtrate into a clean dry beaker and add the following solutions from burettes in the order given :—

10 ml. 50% sulphuric acid.
10 ml. sodium sulphite solution (50 g. in 100 ml. water).
20 ml. 10 N sodium hydroxide solution.
10 ml. potassium cyanide solution (520 g. in 1 litre of water).

Bring the solution to the boil and then add 10 ml. of a sodium sulphide solution prepared by dissolving 1 lb. of Analar sodium sulphide and 40 g. of sodium hydroxide in water, adding 16 g. flowers of sulphur, shaking until all the sulphur is dissolved and then filtering and diluting to 2 litres.

Place a cover glass over the beaker and boil gently for 10 minutes. Pour the solution through a dry fluted Whatman No. 42 filter paper and wash the precipitate twice with a warm wash solution consisting of 10 ml. 10 N sodium hydroxide and 10 ml. sodium sulphide solution in 1 litre of distilled water. Jet the precipitate back into the original beaker with hot water and pour 30 ml. boiling 1 : 1 hydrochloric acid through the filter, washing well with hot water. Boil the solution down to low bulk. Cool and add ammonia (sp. gr. 0·88) until the solution is just ammoniacal. Then add the following solutions in the order given :—

10 ml. sodium sulphite solution (50 g. in 100 ml. water).
20 ml. base electrolyte A.

Make the volume of the solution up to 50 ml., mix well and pour a small quantity (if necessary through a dry Whatman No. 40 filter paper) into a polarograph cell. Add mercury to form the anode pool and place the cell in a thermostat at 25° C. for 10 minutes. Record the polarogram using sensitivities of 100, 50 or 40 microamperes of the Tinsley polarograph. Range −0·8 to −1·5 volts applying 4 volts across the main potentiometer.

Results

To 2·0 g. portions of pure copper each dissolved in 25 ml. nitric acid (sp. gr. 1·20), a standard zinc solution was added to give zinc varying from 1·0% to 5·0%. Method 1 was carried out on these solutions with the results shown in Table I. The graph of the results was a straight line passing through the origin.

The effects on the method of all the other elements normally present in bronzes were next studied. Tin is removed as metastannic acid in the opening out of the method and does not interfere. Some of the iron is also precipitated and removed with the metastannic acid. Copper and nickel remain completely in the filtrate and all but a negligible trace is washed out of the zinc precipitate. However, lead and traces of iron are precipitated along with the zinc sulphide and they cause a precipitate on making the solution ammoniacal prior to the addition of the base electrolyte A. This precipitate is readily removed by pouring a portion of

2 Robertshaw, A., *Analyst*, 1942, **67**, 259.
3 British Chemical Standards, Certificates of Analyses of Manganese Brass "B" issued by the Bureau of Analysed Samples, Ltd.
4 Kolthoff, I. M. and Lingane, J. J., *Polarography*, New York, 1941.
5 Milner, G. W. C., *Analyst*, 1945, **70**, 468–474.

TABLE I.

Zinc %	Height of curve in divisions.		
	S = 100	S = 50	S = 40
1·0	5·5	11·0	13·5
2·0	11·0	22·0	27·25
3·0	16·5	32·75	40·5
4·0	21·75	43·5	—
5·0	27·25	—	—

S = Sensitivity of the instrument in microamperes.

the final solution through a dry Whatman filter paper into the polarograph cell. Investigations have shown that the presence of this precipitate in the final solution does not affect the definition of the zinc polarogram or the accuracy of the result obtained.

Using the calibration graphs constructed from the results in Table I, Method 1 has been applied to the determination of zinc in bronzes complying with many different specifications with the results shown in Column A in Table III.*

The method of removing the copper interference by precipitation and then determining polarographically the zinc left in the filtrate was next investigated. Several methods of removing copper chemically were studied but the most satisfactory method consisted of the precipitation of the copper as cuprous iodide. The cuprous iodide precipitate can be simply and quickly removed along with the metastannic acid by using a centrifuge. This method does not remove the copper completely but is suitable for the determination of all amounts of zinc in bronzes, other than traces. Investigations led to the following rapid method for the determination of zinc in bronzes.

Method 2

Dissolve 0·5 g. bronze in 5 ml. of nitric acid (sp. gr. 1·20), boil out the nitrous fumes and take to low bulk. Dissolve the salts in distilled water and make up to 25 ml. in a standard flask. Pour the solution back into the original beaker and add 25 ml. 15% potassium iodide solution. Mix well, pour into a centrifuge tube and centrifuge out the cuprous iodide and metastannic acid.

Pipette 5 ml. of the filtrate into a 125 ml. conical beaker and proceed in either of the following ways :—

(*a*) Add 2 ml. sodium sulphite solution (50 g. in 100 ml. water) and then ammonia (sp. gr. 0·88) dropwise until the solution is just ammoniacal. Add 10 ml. base electrolyte A, and make up to 25 ml. Pour a quantity of the solution into a polarograph cell and add mercury to form the anode. Record the polarogram using a sensitivity of 20, 10 or 5 microamperes of the Tinsley polarograph, applying 2 volts across the main potentiometer. Range —0·8 volts to —1·5 volts.

(*b*) Add 1 ml. 50% sulphuric acid and several drops of nitric acid (sp. gr. 1·42). Boil and take down to fumes of sulphuric to destroy the iodine. Cool, add several ml. water and make the solution just ammoniacal. Add 2 ml. sodium sulphite solution (50 g. in 100 ml. water), 10 ml. base electrolyte A and make up to 25 ml. Record the polarogram exactly as in (*a*). This method gives curves for zinc which are better defined than those obtained in (*a*).

Results

To 0·5 g. portions of pure copper each dissolved in 5 ml. nitric acid (sp. gr. 1·20), a standard zinc solution was added to give zinc varying from 1·0% to 5·0%. The copper was removed as cuprous iodide and Methods 2(*a*) and (*b*) were applied to 5 ml. portions of the filtrate with the results shown in Table II.

TABLE II.

Zinc %	Height of curve in divisions.					
	S = 20		S = 10		S = 5	
	(*a*)	(*b*)	(*a*)	(*b*)	(*a*)	(*b*)
1·0 ..	5·75	5·25	11·5	10·75	23·25	21·5
2·0 ..	11·50	11·0	23·0	21·5	—	—
3·0 ..	17·25	16·5	34·5	32·0	—	—
4·0 ..	23·0	22·25	—	—	—	—
5·0 ..	29·0	27·5	—	—	—	—

(*To be continued*)

* Table III will appear in the next issue.

Microchemistry Group Meeting

AT the recent meeting of the Microchemistry Group of the Society of Public Analysts and other Analytical Chemists held in the Sir John Cass Technical Institute, four papers were read.

Dr. A. J. Lindsey gave a review entitled, "Electrolytic Methods for Microchemical Analysis." Since the literature on this topic is very extensive, the speaker confined his remarks to the field of gravimetric electrochemical deposition only, qualitative methods and other branches being omitted from consideration.

For many years the development of micro methods followed very closely the classical macro procedures. Consequently, new procedures introduced into large scale work were often not applied to micro-determinations for some time. Usually, workers in the micro field were concerned only with the determination of single metals, and the problem of the separation of metals was attacked only relatively recently. This was unfortunate, since many methods which are excellent for single metals break down when applied to mixtures. Thus, the ordinary electrolytic method for copper fails if arsenic is present.

Micro-electrolytic methods are subject to the usual advantages and disadvantages common to all micro methods. Thus, one has to reckon with the original cost of equipment, in particular of the balance. But the methods are favourable in that the rapidity with which determinations can be carried out applies equally to the large and the small scale, while there is undoubtedly a considerable saving in initial cost because of the much smaller amount of platinum required for electrodes.

The basic theory which covers macro- and micro-electrolytic procedures implies that the activities of the ions being deposited are of first importance in governing the rate of deposition. Since the activity is affected by stirring, we find that rapid stirring is essential in most micro procedures, in particular those which aim at the separation of metals by controlled potential. Such stirring decreases the time required for deposition, and also helps in avoiding the simultaneous liberation of other ions which would affect deposition adversely. Thus, the liberation of hydrogen would give a spongy deposit. Rapid stirring will help to prevent this.

Dr. Lindsey described early micro-electrolytic methods which used such means of determination as the Nernst quartz-filament torsion balance, or microscopic measurement of the final product. The first method to find general application, that of Pregl in 1917, uses a well-known apparatus and achieves stirring by a combination of boiling and the evolution of anodic oxygen. Alternative methods of stirring are provided by inert gas bubbles which may be passed into the system through a coarse glass sinter. Such a device enables deposition to take place at some temperature other than the boiling point of the electrolytes.

The Lindsey-Sand apparatus for controlled potential work uses a large anode which is close to the cathode. Addition of an anodic depolariser permits the retention of a constant anode potential, and hence a precise control of the cathode potential. A modification of this now permits of determination of the *true* cathode potential.

Other specialised apparatus, for purposes such as the determination of minute amounts of cations in large volumes of solution, were also described.

Micro-electrolytic methods have been applied successfully to the analysis of alloys; to the determination of metals in organic substances; to the determination of mixed halides by an electrolytic silver estimation on the weighed mixed halide precipitate. Successful application of electrolysis in combination with other physical methods such as polarography or spectroscopy has also been achieved.

At the present time, successful methods have been worked out for the determination of arsenic, bismuth, cadmium, cobalt, copper, gold, lead, mercury, nickel, silver, tin and zinc.

Dr. Lindsey's lecture was illustrated by lantern slides and by a display of electrolytic apparatus.

Mr. A. E. Heron discussed the "Oxidation of Nitrogen during the Micro-combustion of Organic Substances." The investigation which Mr. Heron described was concerned with determining to what extent nitrogen, not linked to oxygen, is oxidised during combustion of organic compounds. Such oxidation would have a bearing on the results obtained in, for example, coal analysis on the micro-scale.

It was found that when organic compounds of varying types containing nitro, amino, heterocyclic and other classes of nitrogen linkage, all gave appreciable amounts of nitrogen oxides, as did coal. When the combustion of coal was carried out in a porcelain boat, less oxides were found than when a platinum boat was used. No significant difference was observed for pure organic compounds. The packing of the combustion tube with silica chips increased the amount of oxides found, as much as 40% of the total nitrogen being converted to oxides in some combustions. The amount found varied markedly from combustion to combustion.

Mr. Heron emphasised that in consequence of these findings, provision must be made in micro-combustions for the removal of nitrogen oxides, although such provision is not necessary on the macro-scale.

Mr. A. L. Bacharach described a technique which is useful in the micro-separation of gums and crystals. The technique is based on a method used by Tutton to this end, whose precise mechanism is uncertain, but which seems to depend on diffusion. In the modified technique, a Conway diffusion unit is used on the small scale. The mixture of gummy material and crystals is spread on a piece of porous tile and placed in the central chamber, while a volatile solvent such as acetone or ether is placed in the annular enclosure. After some time it is found that the gummy material has soaked into the tile, leaving the crystals relatively clear for further manipulations. Specimen experiments, with controls, which were exhibited by Mr. Bacharach, showed that the separation only took place in the presence of the solvent.

Larger scale apparatus can readily be improvised from ordinary dishes and similar laboratory apparatuses.

The final paper was entitled the "Microchemical Determination of Molybdenum in Steel," by Messrs. J. E. Wells and R. Pemberton.

This paper described investigations of the conditions suitable for the determination of molybdenum using toluene–3 : 4–dithiol. The final determination depends on the amyl acetate extraction of the green-coloured complex and its measurement absorptiometrically. The colour of a properly treated solution bears a linear relation to molybdenum content. Since tungsten may, in certain conditions, give a similar colour, provision has to be made, by the addition of phosphoric acid and careful control of the acidity, to prevent tungsten interference. The coloured solutions which result are stable for at least 24 hours. (Samples exhibited showed that the colour is actually stable for much longer periods than this). The determination, as finally described, permits the determination of molybdenum in a 4 mg. sample of steel, in the presence of tungsten up to 16%; nickel and chromium up to 25%; cobalt, vanadium, tin, lead, tantalum, manganese, aluminium and zirconium up to 10%; silicon and selenium up to 5% and titanium up to 1%. There is a small amount of interference in the presence of copper, while iron also produces a small blank. The results obtained agree closely with determinations on macro samples of 0·1–0·2 g., using the conventional thiocyanate method of determination.

Microchemistry Group, Officers, 1947

At the Annual General Meeting of the Microchemistry Group of the Society of Public Analysts and other Analytical Chemistry held in the Sir John Cass Technical Institute, London, E.C. 3, on Friday, January 31st, Mr. Norman Strafford was elected Chairman. Other office bearers for the coming year are *Vice-Chairman:* Dr. Janet W. Matthews. *Hon. Secretary:* Mr. Ronald Belcher. *Members of Committee:* Professor H. V. A. Briscoe, Dr. J. G. A. Griffiths, Mr. J. T. Stock, Mr. E. J. Vaughan, Mr. C. Whalley and Dr. Cecil L. Wilson.

Polarographic Discussion Panel

A Polarographic Discussion Panel, having as its objects the holding and the sponsoring at informal discussions on the subject of polarography as applied to chemical analysis, has been formed by the Physical Methods Group of the Society of Public Analysts and other Analytical Chemists. Plans are in hand to arrange a first meeting in London during April. Particulars may be obtained from the Honorary Secretary, Mr. J. T. Stock, Chemistry Dept., L.C.C. Norwood Technical Institute, Knight's Hill, London, S.E. 27.

The Effect of Phosphorus on the Properties of Gunmetal-reducing Conditions

By R. A. Colton & B. M. Loring

THE use of phosphorus as a deoxidiser in bronze manufacture is wide-spread, but there is sufficient disagreement among foundrymen as to how to use it and why it is used to indicate that there is a scarcity of factual data about the effects of phosphorus in gunmetal. To obtain such information an investigation has been carried out to evaluate phosphorus as a deoxidising agent for gunmetal, to estimate the effects of residual phosphorus on the mechanical properties of gunmetal, to determine the value of phosphorus as a degasifier and to measure the effect of phosphorus, when used as a deoxidiser, on the running quality of gunmetal.

Two test bars, 6 in. × 1 in. diameter and one test bar 6 in. × 1 in. × 1 in. of Navy G gunmetal containing 88% copper, 8% tin, 4% zinc, were cast in a synthetic sand mould. The ingot metal was made in 225 lb. heats in a lift-coil induction furnace from electrolytic fire-refined copper and pure zinc. All experimental heats were made in a 50 lb. Ajax induction furnace in magnesia crucibles. The practice consisted of melting down 50 lb. of ingot metal, adding 4 oz. of charcoal to the surface of the bath, bringing the bath to a temperature of 1225° C. and pouring into a preheated clay-graphite crucible in which a weighted amount of 15% phosphor-copper, wrapped in copper foil, had been placed. The ladle was allowed to stand until the metal temperature had reached 1150° C. and two moulds were then poured. By using this technique test bars with 22 different phosphorus contents in the same base alloy composition were obtained.

From each of the test castings, the cylindrical bars were machined to 0·875 in. diameter and 5·5 in. length and used for measuring specific gravity, after which they were machined to standard 0·505 test bars for tensile strength, yield strength and elongation. The third bar from each casting, that of square cross section, was machined into four standard Charpy V-notch impact specimens which were broken at room temperature. The running quality or fluidity was measured with a spiral mould made of core sand and oven dried, and melting and casting procedure was such as to make the adding of the phosphor-copper to the metal the only variable. The phosphor was added, 2½ oz. of 15% phosphor copper (approximately 0·025% phosphorus) in four ways: (1) sprinkled on the metal surface; (2) sprinkled on the surface and stirred vigorously into the metal; (3) wrapped in copper foil and plunged under the surface of the metal with a bell-shaped plunger; and (4) wrapped in copper foil, placed in the bottom of a preheated clay-graphite crucible, and the metal poured over the phosphor-copper. The metal was poured at five successively decreasing temperatures and the time

TABLE 1.—DATA FROM TESTS (AVERAGE VALUES)

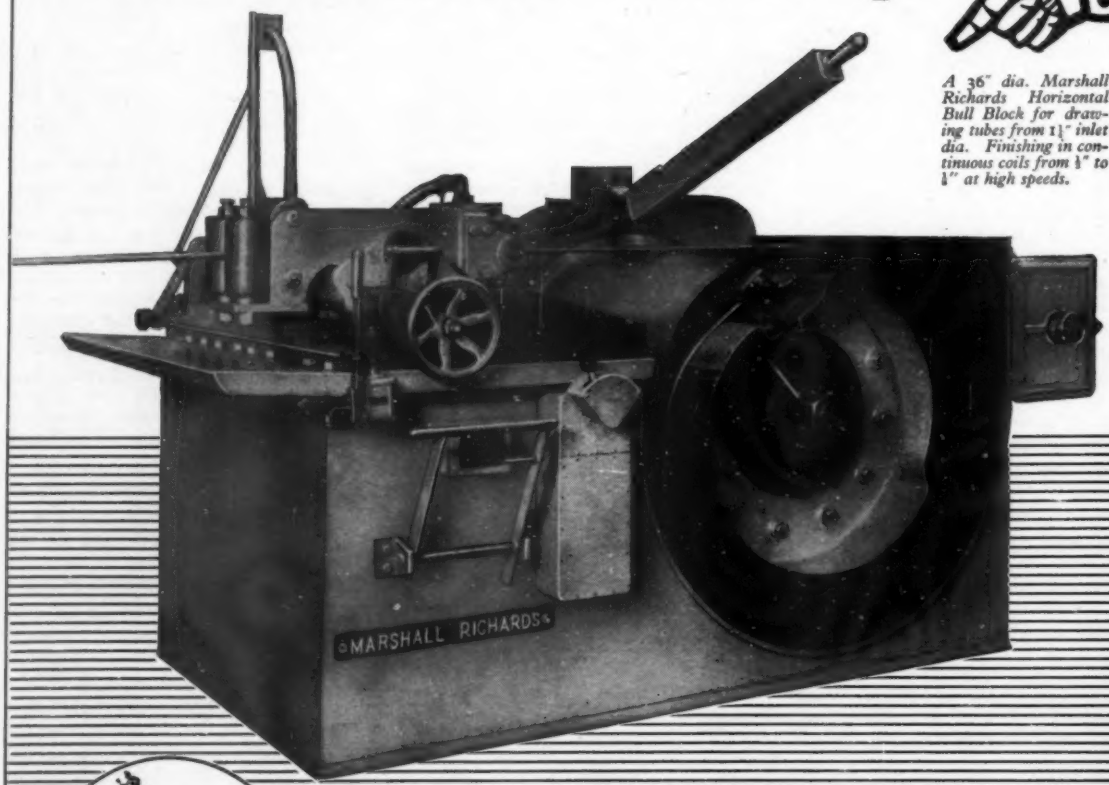
Test No.	Phosphorus Added %	Residual Phosphorus %	Specific Gravity 20° C.	Yield Strength 0·1% Offset	Tensile Strength Tons Per Sq. In.	Elongation % on 2 in.	Charpy Impact Ft. Lb.
106	0	0	8·52	7·1	16·0	26·5	27·0
84	0·0093	0·008	8·58	7·4	17·7	31·5	30·0
86	0·0187	0·014	8·57	7·5	17·9	31·5	25·5
88	0·0280	0·023	8·51	7·4	17·8	32·5	26·5
90	0·0374	0·035	8·40	7·1	16·3	26·0	25·0
92	0·0467	0·040	8·46	7·4	16·6	24·5	25·5
94	0·0561	0·051	8·44	7·1	17·1	28·0	26·5
98	0·0750	0·075	8·29	7·0	15·8	23·5	22·0
100	0·0841	0·079	8·31	7·0	16·1	24·0	22·0
102	0·0935	0·089	8·30	6·9	15·1	22·0	23·0
104	0·112	0·106	8·26	6·9	15·3	21·5	22·0

TABLE 2.—RESULTS OF FLUIDITY TEST.

Test	Method of Adding Phosphorus	Pouring Temperature ° C.	Time between Pourings after Phosphorus Additions	Spiral Length In.	Phosphorus %
F.1	Cu-P wrapped in foil and plunged into Bath	1150	—	30·5	0·024
F.2		1125	—	23·5	0·023
F.3		1100	—	19·5	0·023
F.4		1075	—	12·5	0·022
F.5		1045	—	9·5	0·020
F.6	Cu-P sprinkled on surface and stirred in vigorously	—	1:23	34·0	0·016
F.7		1175	2:22	30·5	0·018
F.8		1150	3:10	26·5	0·017
F.9		1105	4:22	22·0	0·016
F.10		1067	5:26	9·5	0·020
F.11	Cu-P sprinkled on surface	1220	0:55	36·0	0·020
F.12		1185	2:15	32·0	0·019
F.13		1140	3:42	25·5	0·018
F.14		1100	5:02	19·0	0·016
F.15		1055	6:25	8·0	0·016
F.16	Metal poured over Cu-P	—	1:32	36·5	0·018
F.17		1195	3:49	34·0	0·014
F.18		1155	5:06	30·0	0·013
F.19		1120	6:08	26·0	0·012
F.20		1080	7:25	16·0	0·010
F.21	No P.	1210	0	29·0	—
F.22		1180	0:30	23·0	—
F.23		1145	2:00	19·0	—
F.24		1105	3:20	14·0	—
F.25		1070	4:18	12·0	—
F.26	No P.	1205	0	30·0	—
F.27		1168	1:07	23·0	—
F.28		1130	2:10	18·0	—
F.29		1080	3:43	12·5	—
F.30		1040	5:00	4·0	—

From *Metals Technology*, 1946, Vol. 13, No. 4, and *A.I.M.M.E. Technical Publication*, 1974, pp. 1–13.

Here's the Bull Block for the Tube Industry!



A 36" dia. Marshall Richards Horizontal Bull Block for drawing tubes from 1½" inlet dia. Finishing in continuous coils from ½" to ¼" at high speeds.

No push buttons • Single lever control for economic production. *The Marshall Richards 36" Horizontal Bull Block is a unique machine. May we send you particulars? Please write to Marshall Richards Machine Co. Ltd., Crook, Co. Durham, England. Telephone: Crook 206.*

interval between pouring castings recorded and the length of the spiral measured. Two heats were made with no phosphor-copper added. In Tables I and II are given the average test data obtained and the results of the fluidity tests.

From the results obtained it is shown that most of the phosphorus added to gunmetal under the conditions used was retained by the metal. From this evidence it appeared questionable whether the phosphorus was actually serving as a deoxidiser, a view which appears reasonable due to presence of 4% of zinc, a strong deoxidiser in its own right. Small amounts of residual phosphorus up to 0·02% were found to increase the specific gravity of the metal, while greater amounts caused a gradual decrease. This decrease might be due to the lowering of the solidus increasing the solidification interval and allowing a greater formation of interdendritic cavities. It would also probably cause increased segregation in the metal.

With up to 0·02% residual phosphorus in the metal, there was considerable improvement in tensile strength, yield strength, and Charpy impact values, but larger amounts of phosphorus caused poorer properties. The increase in mechanical properties with the small amounts of phosphorus was considered to be due to the strengthening action of the phosphorus in solution, while the decrease was probably due to changes produced by unsoundness and increased segregation.

From the results of the fluidity experiments, it appeared that phosphorus had a definitely beneficial effect on the running of the steel. The best method of adding the phosphorus was the one that ensured both thorough mixing and protection of the phosphorus from atmospheric oxidation. Experiments on the running quality also indicated that holding a heat of metal in a crucible for about six minutes while the temperature dropped from approximately 1250°–1050° C. did not greatly decrease the phosphorus content.

Flame Hardening Cast Iron

By R. H. Olmsted

OF the large number of irons of different compositions which are classified as grey cast iron, only these which have sufficient hardenability characteristics in the casting section are suitable for the flame hardening process. These are principally the so-called pearlitic irons containing 0·6 to 0·8% carbon. Low silicon and, even more important, low total carbon also favour maximum hardness, which, measured with a Rockwell instrument or scleroscope and converted to Brinell hardness, can attain hardness numbers in the range of 550 to 600. In Fig. 1 is given a curve of flame-hardened Meehanite iron showing the surface hardness and hardness at various depths below the surface. A general specification for alloy cast irons suitable for flame hardening has been given as 3·30% total carbon, 1–2% silicon, 0·6–1·0% manganese, 1–2% nickel and 0·75% of chromium plus molybdenum and vanadium.

Along with composition, a second basic consideration for the selection of an iron suitable for flame hardening is the cleanliness of the iron. The casting must be free of sand or slag in the sections to be selectively hardened,

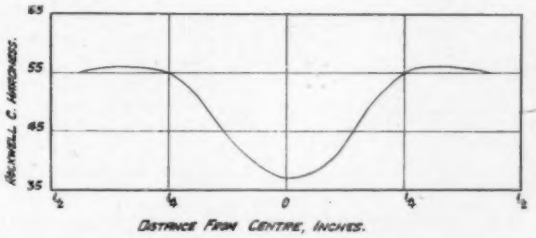


Fig. 1—Cross-sectional diagram under same operating conditions—power input 15 Kw., surface temperature 815°C specimens normalised and tempered.

as even minute small particles of sand, not visible to the eye, will explode during quenching and are liable to leave a rough surface. Minute porosity of the iron will also increase the surface exposed to the exceedingly hot flame, 3,300° C. or more, and may heat that area to a temperature at which sweating or even melting might occur.

Flame hardening of grey iron is generally performed on heavy castings thick in section or complicated in shape and unsuited for other methods of hardening. If wear resistance is the chief reason for hardening, only certain sections require high hardness in most cases, so that their selective hardening by the flame method is most suitable. For efficient hardening speeds of torch and quench travel, oxygen and acetylene pressures, volume of quenching medium and distance of the torch and quenching equipment from the work are a few of the items which must be held within rather close limits. The hardenability critical temperature and heat conductivity of each type of iron have also to be considered.

Iron castings, owing to their usual design and to the physical characteristics of the solidifying metal, contain considerable stresses, especially in the high strength types and require to be given a stress relief treatment at as high a temperature as possible (650° C.) without structural change before flame hardening. After flame treatment many castings have been successfully put into service with no low temperature stress relief treatment so as to retain their maximum hardness. A stress relief treatment at 150° C., however, is generally recommended. Compared with the more common methods of heat-treating cast iron, flame hardening usually presents fewer problems of distortion, primarily due to the fact that in most instances of flame hardening only a relatively small proportion of the entire casting is subjected to temperatures at which distortion would take place.

The flame hardening of machine toolways is one of the outstanding applications in the field of grey cast iron. Many other machine tool parts and jigs and fixtures are also so hardened to maintain close tolerance during subsequent use, by reducing the possibility of gouges or scratches.

From *The Foundry*, 1946, Vol. 74, No. 5, pp. 152–155, 284 and 286.

Caesium

CAESIUM belongs to the alkali metals, the common ones in this group being sodium and potassium. In its simple salts and simple chemical reactions caesium resembles potassium very closely. However, it differs from potassium and sodium in the properties of the complex salts many of which are comparatively insoluble in water, as against the equivalent potassium or sodium salts. Even the chloroplatinate of caesium is more than ten

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times as insoluble as the chloroplatinate of potassium. Furthermore, in plant life, and in living cells in general, potassium is an essential constituent whereas caesium is a poison.

The element was first isolated by Bunsen and Kirchhof in 1860. In the spectroscope two characteristic blue lines were shown and hence the name "caesium" was given to the element. In nature the element is relatively rare; it occurs in the mineral pollux or pollucite, which is a hydrated aluminium caesium sodium silicate containing from 30–36% caesium oxide containing from 30–36% caesium oxide. This is found at Hebron, Maine, in the Black Hills of South Dakota, and in Sweden. Caesium is recovered from this mineral by treatment with hydrofluoric acid and then precipiated out of solution by the addition of antimony trichloride ($3CsCl : 2SbCl_3$). The corresponding rubidium salt is relatively soluble. Caesium also occurs in some of the lepidolites and in some of the carnallites. Metallic caesium can be prepared by various methods, the older ones comprise the interaction of caesium chloride or caesium carbonate with metallic magnesium or metallic calcium in the presence of hydrogen which carries away the caesium vapour as formed and in that way pushes the equilibrium toward the caesium metal side. In the vacuum tube factories other methods have been introduced: thus Philips uses the nitride method starting out with BaN_6, interacting that with CsCl heated in vacuum. At about 150° C. the nitride of barium dissociates, furnishing barium metal which, on further heating to about 350° C., reacts with the caesium chloride to produce caesium metal.

Another method in use comprises introducing into a very small nickel crucible a mixture of caesium chromate, zirconium metal powder, chromic oxide and aluminium powder. The crucible is attached to the lower part of the stem of the phototube and after the tube has been evacuated and sealed the mixture is heated up to reaction temperature.

Practically all of the caesium produced to-day is consumed in the production of photoelectric cells or "electric eyes." The caesium cell is about 14 times as sensitive as the older hydrogenated potassium photoelectric cell. More specifically, the modern caesium cell has an average sensitivity of 60 microamperes per lumen. An increase in the quantum yield is obtained when a foreign metal is present in the caesium-caesium oxide cathode layer. Silver is one of the metals commonly used. For a Cs-Cs oxide-Ag sensitised layer the maximum emission is at about 7,500 A for mirror surfaces and at about 8,600 A for rough surfaces. The caesium photoelectric cell will fatigue under certain circumstances but the cell is revived by rest in the dark or by heating.

Fluorine: Its Preparation, Handling and Application

AT the time of the first World War, the preparation of fluorine had been developed little beyond the methods of Moissan and other early workers. It could be made only at great cost in quantities of a few grams by electrolysis at platinum electrodes of liquified HF containing a small amount of KF at a temperature of —25° C. or lower. Mathers and others introduced the use of graphite electrodes and molten KHF_2 electrolyte, which could be electrolysed at about 250° C. Le Beau improved the Mathers cell by using electrolyte with the approximate formula KH_2F_3, thus permitting operation at only 100° C. in spite of these improvements, however, fluorine remained a rare and costly chemical.

In 1940, the need for tonnage quantities of fluorine for preparation of volatile uranium compounds caused work to begin on developing the intermediate temperature cell to commercial status. Many difficulties were readily overcome by use of a steel cell container, steel cathode and Monel screen diaphragm. Development of an anode which would withstand conditions of fluoride electrolysis, give a good yield of fluorine, and at the same time provide necessary conductivity and other physical characteristics proved to be the major problem.

Nickel was satisfactory except that it corroded over long periods of operation and fouled the electrolyte. Graphite was unsatisfactory because of its tendency to react, swell and break in the presence of fluorine. Ungraphitised carbon from petroleum coke largely eliminated both the corrosion encountered with nickel and the breakage of graphite, advantages which outweighed difficulties of connecting carbon and its inoperability in the presence of fortuitous traces of water. Difficulties in making electrical connections have been largely eliminated by use of the present carbon electrode which is impregnated with metallic copper. Water can be removed by a preliminary period of operation with nickel electrodes. One further difficulty encountered with carbon electrodes—namely, polarisation in the sense of sudden voltage increase and resulting loss of efficiency, has been solved by incorporating LiF in the electrolyte, perhaps to act as a wetting agent.

Thus, in a few years fluorine cells capable of commercial operation without skilled attention have been developed from very small beginnings. The Harshaw cell, for example, measuring about 6 ft. × 2 ft. × 1½ ft., and containing 96 carbon-copper anodes, is capable of continuous operation for periods upwards of a year. Requiring a temperature of only 95°–115° C., it can be heated with a water jacket. Up to 1,500 amperes are consumed at 9–9·5 volts, with current efficiency of 95%.

If organic matter is avoided, fluorine can be handled in steel, nickel, Monel, copper, aluminium and magnesium. Because of its low critical temperature, it must be stored as a compressed gas rather than a liquid. Pressures up to 2,000 psi can be obtained by condensation in liquid nitrogen and subsequent evaporation; lower pressures of the order of 100 psi by mechanical means. However, high pressure fluorine is considered a hazard, pressures not to exceed 30 psi being recommended.

Exploration of the potential applications of elemental fluorine has scarcely been begun. Fluorocarbons have been prepared by reaction of hydrocarbons with a regeneratable fluorine carrier such as CoF_3. They are remarkable for their high chemical and thermal stability, low refractive indices, high densities and low boiling points. Among inorganics, sulphur hexafluoride is of interest as an insulator, and ClF_3 and BrF_3 have been prepared.

From *Bull. Electrochem. Soc.*, Jan., 1947. (Synopsis of address by Dr. J. T. Pinkerton before Cleveland Section).